SCIENCE TODAY

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THE SCIENTIFIC OUTLOOK ON WORLD PROBLEMS
EXPLAINED BY LEADING EXPONENTS OF
MODERN SCIENTIFIC THOUGHT

PLANNED AND ARRANGED BY THE LATE

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PREFACE

SIR ARTHUR THOMSON did not live to see the completion of this survey of contemporary science. He designed the scheme of the book and discussed the subjects and the method of presentation with many of the contributors. In this way his great talent for popular exposition was to be combined with the authority of the contributors in their own particular fields of research. As an expositor of biological science Sir Arthur Thomson was in his time unsurpassed. He was a Scotsman, and acquired in the process of a Scottish education all the skill in lecturing that his own talent and the Scottish educational tradition could give him. After he graduated at Edinburgh University he lectured at the Edinburgh School of Medicine on biology. He also rapidly became a popular lecturer to audiences in the neighbouring towns. Like other young Scotsmen of his time, he was influenced by R. L. Stevenson. He became interested in the literary presentation of science. Thomson's remarkable combination of scientific knowledge with expository and literary ability became evident early in his career. He was appointed the Regius Professor of Natural History in Aberdeen University while he was still in the thirties. His elementary lectures at Aberdeen became famous, and nearly all students from all departments made a point of hearing some of them. Unlike T. H. Huxley and Milnes Marshall, he did not lecture on types of animals so much as on biological topics. He discoursed on topics such as the conquest of the land and the balance of life, unfolding his knowledge in the form of a story. He spoke with a rich Scottish accent in a low rhythm, and his audiences listened with rapt attention as he approached the climax of his drama, breaking into occasional applause as he turned the argument around some extraordinary pheno-

menon of life. He could describe natural phenomena in a simple, flowing style, which seemed to float his audiences and readers over a subject.

His long series of books included *The Evolution of Sex*, which he wrote in collaboration with the late Sir Patrick Geddes; the Gifford Lectures delivered at St. Andrew's University and given the title of *The System of Animate Nature;* the large volumes, *Life: Outlines of General Biology,* also written in collaboration with Sir Patrick Geddes. The best known of his more popular books is *The Outline of Science.* It had an immense success, and did much to stimulate the admirable public taste for summaries of scientific knowledge. Other popular books by him are *The Science of Life, The Biology of Birds*, and *The New Natural History.*

Sir Arthur Thomson received many honours. He gave the Terry Lectures in Yale University in 1924. Honorary degrees were conferred on him by the Universities of Edinburgh, McGill, California, and Aberdeen.

Science Today is the last effort of Sir Arthur Thomson to fulfil the task for which he was naturally endowed: the exposition of science to the people.

J. G. C.

INTRODUCTION

THE modern world is in turmoil. Every aspect and activity of life is changing rapidly. Industry, politics, science exhibit within their spheres the changing activity seen in the totality of human life. In the modern world science is peculiarly important, and has more influence on life than in any other historical period. The most important of modern cultural pursuits may be expected to show with special emphasis the changing activity characteristic of the times. What has science to say concerning man himself? What is the state of knowledge concerning man? How is this knowledge changing and in what direction? What are the answers to similar questions concerning the methods, the philosophy of science? Do the fundamental concepts of science show a change? The status of determinism, of causality, must be discussed. If the status of these concepts is changed, the concept of nature is changed. These notions are the frameworks by which nature is seen, the scaffolding through which contact is made with the universe. Besides considering modern scientific knowledge of man and his intellectual mechanism, the newest information concerning his environment must be considered. Accepting without question the efficiency of the methods employed in scientific study, the new facts revealed by application must be reviewed. The methods of science may be eternal; it is not necessary to suppose that the methods change in order that further scientific knowledge should be gained. A continual increase in scientific knowledge through the steady application of eternal methods is not inconceivable, though improbable. The new knowledge concerning the environment of man, the nature and scale of the universe which contains him, the earth which bears him, and the materials of which he and his environment are made, must be reviewed. When this has been done

the place of science may be assessed. Its relations to regions outside or beyond its sphere may be discussed. The student of such discussions can consider the state of modern scientific knowledge as an outcome of centuries of scientific work. He can see where science has arrived and learn the peculiar perspective in which it reveals the present and the future of man, his ideas and his environment.

The late Sir Arthur Thomson designed this book to provide the serious but non-specialist reader with a series of discussions of the state and outlook of modern science in its main branches. Each essay has been contributed by an authority eminent in exposition besides learning. The contributors have been sought in many countries.

A successful guidance of the changes in modern life is the chief need of the day. An acquaintance with the changes in science and the scientific accounts of the various aspects of life will help man to discover how this guidance should be made. When man is involved in material and spiritual turmoil he needs strength to accomplish the achievement of control. He should be given confidence in his own abilities. This is done best by helping him to understand his own powers and for a while encouraging him to consider himself. In periods of stability when the possibilities and duties of man are fairly clear he had better concentrate on the accomplishment of what clearly should be done. He need not think of himself because his duty is obvious. When life is clear and stable it is relatively easy and man has confidence in his ability to manage it; he need not give much attention to his personal problems, but devote himself to the performance of objective duties. This happy attitude is not possible in periods of change. The prospects of life change; man often finds them too difficult and becomes afraid of them. The essays in this book are arranged in consonance with the view that men must proceed from themselves outwards in a period of change. He must understand his own potentialities and be inspired by new knowledge concerning himself. A discussion of heredity in human affairs is the point of departure in the journey through the regions of modern science. After discussing this

most active of the branches of the biology of human nature, other biological aspects of human nature are considered—those involved in medicine and general anthropology. After learning of the general biological aspects of man physiology may be appreciated, and physiology is the appropriate preceder of psychology. With a knowledge of heredity, medicine, anthropology, physiology and psychology, sociology may be studied, and then an essay on an important aspect of sociology—theology. This completes the survey of the sciences in which man himself is an important object of study. After the study of the sciences of man follows the study of the sciences of his environment, and is started with chemistry, which describes the properties of familiar matter. This is followed by physics, which is concerned with the quantitative aspects of matter. After learning of the nature of familiar matter, the nature of the earth, which bears humanity, is discussed. Geology is the next discipline. After the earth the stars are considered, in order to find what place the earth occupies within the universe. With a knowledge of the facts of the sciences of man and his environment reflection is appropriate. The techniques of the sciences which have provided these facts must be scrutinized, so mathematics, logic and causality must be studied. An insight into fact and technique allows their meaning to be discussed, so the journey ends in philosophy, and the journey from the concrete to the abstract is completed. This order is the reverse of that often followed in general surveys of knowledge. There is a tendency to assume that the abstract sciences are more important than the concrete sciences, that the more different is the subject-matter from the common things of life, the more profound and important is the science. This tendency exhibits in some degree a contempt for humanity, a philosophical priggery. It implies that non-human things are more important than human things. This is not the attitude to be suggested by this book. Man should realize the extent of his knowledge of himself and the external world and take courage from his achievements to face the difficulties of the day. From this he may proceed to the successful control of a more complicated world

and therefore to a more interesting life. If he loses confidence and retreats from the complications of an interesting world and calls for a simplified world equal to his demeaned abilities he will fall into retreat. The life of society and the intellect will be cheapened and humanity will decline or remain stationary for a long period. Professor Lancelot Hogben starts the review of Science Today with an acute statement of present knowledge of the biology of human heredity. His contribution is peculiarly timely. He is an extremely active research worker in this field, and what he has to say comes straight from the workshop of science. This is his first general review of a field to which he has devoted years of research. He is one of the three or four biologists in the world who are equipped to make important contributions to the biology of human heredity. This subject can no longer be usefully discussed without a considerable acquaintance with mathematics, and few biologists are also mathematicians. Besides a knowledge of biology and mathematics the effective worker must have a wide and active apprehension of the common affairs of human life. He must be able to see which aspects of human affairs are both important and susceptible of scientific treatment. Few of the facts of human and other nature are at present amenable to scientific discussion; the technique of science is as yet not developed enough to give useful knowledge concerning more than a few of the facts which are the raw material of science. Exceptional judgment or general intelligence is necessary in order to select these facts of human heredity which may through scientific discussion provide an insight into the social possibilities beyond the present social facts. But this is not enough. The facts of human nature are extremely complex and therefore cannot be discussed scientifically without mathematical analysis. Professor Hogben has recently shown mathematically that it should be possible to learn a great deal more about the hereditary characteristics of men than had been believed. The study of human heredity is complicated by the absence of experiment. Scientists are not allowed to control the mating of men and women, so they must deduce the peculiarities of

their hereditary constitutions from an analysis of the characteristics of human families as they are found. The science of human heredity is consequently a science of secondary details, in which progress must be made by deep mathematical analysis of the related characters of cousins, twins and other remote or special examples. The material of the science is one of the least amenable to the intuitions of common sense. General intelligence is very necessary in the student of human heredity, but it will carry him much less farther in his studies than the experimental physicist can be carried by general intelligence in the study of atomic constitution. Mathematics is even more important in heredity than in physics because human prejudice is much more likely to distort the understanding of man than of things. With his wide intellectual equipment Professor Hogben is able to show that racialist theories of society have no scientific foundations. They may be right or they may be wrong, but as yet science cannot decide. He concludes that the sociological behaviour of man is probably influenced as much by the acquisition of habits as by hereditary constitution. If social organization is to be improved, it will be done through the learning of different habits rather than by breeding a new sort of man. The central nervous system by which a man co-ordinates his behaviour more probably contains the solution of the problems of sociology.

Sir Leslie MacKenzie prefaces his review of medicine with interesting comments on the work of the chief historical figures. He shows how Hippocrates introduced or greatly emphasized scientific method in medicine by directing study to the actual patients. Careful records of the course of diseases were made, and the treatment of subsequent cases was based on the facts of the previous records. This process of observation to obtain facts upon which forecasts could be made was strictly scientific. Hippocrates said in an extant work that unsuccessful experiments besides successful experiments should be recorded, because it is necessary to know the causes of failure. Here he was emphasizing the necessity for objectivity in scientific observation. Hippocrates made some

of the earliest contributions to scientific philosophy besides medicine. In his work and that of his school the contributions towards the construction of a scientific method are almost as important as his contributions to medicine. The debt of science to medicine is particularly clear in the Hippocratic writings. Six hundred years later Galen in his treatises showed a great extension of medical knowledge and method, to be expected after the experience of six centuries. His intellect was not as brilliant as that of Hippocrates, but he was industrious and original. He collected all the known medical knowledge. The mere accumulation of facts and recipes began to provide the possibility that medicine might become an experimental science. Paracelsus extended the experimental method in a revolt against Galen's authority. He contended that alchemy should be justified not by attempts to make gold and silver, but to provide the supreme sciences which could be directed against disease. He clearly expressed the modern idea that the practice of medicine should be based on scientific research, as partially distinct from medical research. Not all research of importance to medicine should be made by doctors. Medicine should be founded on the supreme sciences of chemistry, physics, etc., and these should be cultivated by their own professors. The emancipation of scientific research concerned with medicine from the prerogative of medical doctors resembles the emancipation of learning from the church. In earlier periods the study of philosophy and learning was confined to the religious clerks. By a short explanation of the contributions of the chief medical geniuses in history Sir Leslie MacKenzie prepares the reader for an account of modern medical research and the advances in medical technique. The general reader will learn something of the developments in diagnosis, in teamwork and in other aspects of modern medicine.

Dr. Marett concludes in his review of Anthropology that religion is concerned with man's orientation towards the unknown. Its function is to maintain awareness of the importance of the unknown as the source of the new. A failure of religion causes a loss of respect for the unknown and a change

of attention from it to the known. It implies a loss of belief in possibility, and hence in progress and development.

The facts of anthropological history suggest that mankind has, on the whole, succeeded in the pursuit of good; which gives the point to life. The certainty of this fundamental conclusion is reinforced by the objectivity of anthropological methods of investigation which, unlike those of ordinary history or the history of civilization, have the detachment of a science. Anthropology is to be classed with the biological sciences, and possesses their natural historical method. The importance of anthropology is in its breadth and objectivity, which give unequalled confirmation to the belief in the value of life, the basis of culture.

Professor Leathes shows how the science of physiology has grown out of the need of medicine to understand the human body. Medical treatment could not be restricted to the external marks of disease; it required to be directed towards the origin of the disorder. This could not be done without a knowledge of its constitution, structure and mechanism; and the motive led to the development of the sciences of chemistry and biology. Physiology is the basis of modern medical knowledge. Professor Leathes explains why experimentation on animals has been so important in research, and why the physiologist should be acquainted with the sciences of plant and animal behaviour. He gives in some detail an account of several important physiological mechanisms, such as the circulation of the blood. What is the effect of descriptions of the mechanics of the body? The reader is profoundly impressed by their subtlety. The arrangements of a living body for meeting its tasks in life are of a bewildering complexity and perfection. Adjustment is qualified by adjustment, and this adjustment by yet another, until an infinitude of interactions merges into the quality named living. Thus an adaptive power of indescribable subtlety becomes an outstanding or definitive characteristic of a living body, of life. The student of physiology learns a standard in the science of organization. He sees in the human body a superb organization of unit cells. And yet a great deal of this organization

operates without consciousness. Even the bodies of the lower animals exhibit a comparable degree of organization. If all this is operated below the level of consciousness, what is the importance of conscious organization or planning? Professor Leathes finds that the extraordinary degrees of organization below the level of consciousness revealed by physiological research are a ground for caution in estimating the value of conscious planning. Much is heard today of the necessity for conscious planning. Physiology shows that in the evolution of the human body a marvellous degree of organization has been achieved without conscious planning, which seems to suggest that the proper method of evolution may be a method of subconscious adjustments. The proper method of social evolution may, by analogy, also consist of subconscious adjustments. As the human mind cannot as yet grasp more than the barest outline of the organization of the bodily structure, may not the human mind be rash when it tries to produce rational schemes of society? May not these be lacking in the infinite subtleties necessary for the perfect organization of living beings, and which in evolutionary history were not consciously produced?

Professor Lloyd Morgan discusses the delimitations of the science of psychology in order to discover what lies beyond it. He explains that the science of physics deals with a closed system of material entities. It sets forth the laws which describe the sequence of events in the material world. As the entities in the material world are supposed to exist whether they are observed or not, they may be considered to move within a closed system, to which an observer is not essential. In the same way psychology deals with the contents of a closed system of entities known to mind, to a closed system of ideas. When psychology and physics are defined in this manner they are conceived as descriptions of the sequence of events in two different types of region. Both are concerned with the description of what happens in their appropriate region, one with a sequence of ideas and the other with a sequence of events. Laws summarizing the respective sequences are discovered and used to forecast future occur-

rences. The psychologist will say what is to be expected as the outcome of a given sequence of ideas, and the physicist will say what is to be expected of material bodies when they have been in certain conditions. Both psychology and physics describe how something behaves and not why that something behaves. It is clear that science, as exemplified by the sciences of psychology and physics, ignores the factor of activity, the agent which makes things behave, or the quality in them which accounts for their behaviour, their behaving quality. Activity is therefore outside and beyond science. It may in theology be identified with the divine principle. The psychologist need have no difference with the artist, historian or theologian who finds the explanation of his system in terms of the directive activity of human or divine agents.

Mr. Christopher Dawson gives a critical examination of current conceptions of sociological science. He contends that most of the current theories of sociology fail in important points to possess the characteristics of a scientific theory. The creation of a genuinely scientific theory of sociology is probably the most important cultural need of the day, as the failure to produce a scientific sociology implies that society and human culture cannot be comprehended by science. If that is so, scientific civilization is impossible because there can be no theory upon which practice may be founded. Modern civilization is not scientific because, in spite of the huge development of science, scientific method is not employed in the organization and practice of politics. Mr. Dawson does not consider the previous failure to create a scientific sociology implies that such a sociology cannot be created. He finds the explanation in the nature of the material of sociological science. Like zoology, sociology is presented with an enormous quantity and variety of material which confuses the student. Some methods of handling and comprehending the material are needed. Immense labours were done in biology before the theory of evolution became established, and equal or greater labours may be necessary in sociology before similar general laws emerge. Frederic Leplay's sociological method is probably the most promising. He studied

at first hand the social and economic organization of families of different social and national types. This provided valid material for the construction of a genuine scientific theory of family life. Similar methods should be applied to the larger social units such as the rural community, the city and the state.

The Rev. M. C. D'Arcy reviews the present state of the relations between science and theology. He contends that the recent difficulties which have arisen in the philosophy of physics have reduced the exaggerated claims of the scientists concerning their monopoly of knowledge; they have begun to realize again that the scientific method is only one of those capable of attaining truth. The tremendous successes of science during the last three hundred years have blinded many to the philosophical sacrifices by which these successes were purchased. Bacon and his successors flung over the attempt to reach a synthetic view of the world, they refused any longer to dance in the philosophical rings propounded by the ancients. They ignored the view of things as a whole and concentrated on the study of particulars. This anarchism was at first attended by immense scientific achievements, but has now led to unwieldy developments of isolated branches of science. After three centuries of concentration on their subject physicists have found themselves forced to consider the nature of their first principles. Success had caused them to believe that everything might be explained by these principles, but it is now clear that the principles of physics are not the basis of the world, but a limited technique for understanding merely a part of it. As theology could not be reduced to a part of the philosophy of science, it could not be accepted as a fundamental branch of knowledge by those who regarded science as the only basic knowledge. Theology could have no place in the philosophy of those who believed science had the exclusive route to reality. The attempts to base theology on science must always be sterile. Now that the limitations of science are beginning to be appreciated the development of an adequate modern theology is possible.

Mr. D'Arcy's essay completes the review of the sciences in

which man himself is an important subject. It is followed by the first of the reviews of the sciences of man's environment.

Professor Masson's essay on chemistry introduces this section. He describes very simply some of the leading ideas of chemistry and finds the chemists' fundamental motive to be a desire to make a picture of the mechanism of phenomena. The chemist starts from the qualitative properties of materials. Qualitative differences between materials are particularly important in chemistry. In physics they are also fundamental, but the quantitative aspect has a greater part in physics than in chemistry. The chemist learns the precise qualities of the material environment of man. He is concerned with the preparation of pure specimens of the elementary materials of this environment. When he has precisely determined the qualities of matter he proceeds to the analysis of its structure. The atomic theory of the structure of matter was first developed by Dalton, who was a chemist. It has gradually passed into the hands of the physicists, as the theory of the structure of matter became more and more remote from the qualitative account of matter from which it started. Professor Masson finds that chemistry as such can have no particular implication beyond itself. He believes chemistry cannot determine the nature of ultimate reality. The chemist cannot indulge in philosophy without abrogating the principle which governs his working life. The practice of chemistry shows that no man can safely trust his cogitation about nature. Scientific scepticism is the root of scientific method; it is not an axiom or an article of faith, but simply the austere wisdom born of millenia of experience.

In his essay on the Trend of Physics, Professor Eve sketches the ideas which have had so profound an effect on modern thought. He describes, as far as they can be described in words, the notions of the new wave-mechanics of matter. He explains that the waves of the new wave-theory are not material waves. They are not analogous to waves in any medium, such as waves in the sea, or sound-waves in air. They are quite different in nature from the waves which physical theory hypostatizes for the explanation of radio

transmission. Ether-waves are a convenient hypothesis. If such a thing as an ether existed, waves in it would have effects similar to radio waves. The new waves connected with matter have not even the degree of reality possessed by radio waves; they are waves of probability. The new wave-theory of matter does not state that matter is made of a sort of wave, but that the appearance, the being, of matter in any place is governed by waves of probability. The chances that matter may appear in any particular place can be calculated by the new mechanics. Modern experimental observation has shown that the exact position of a particle cannot be determined, not because methods of observation are inexact, but because all methods of observation interfere with the particle, so that at the end of the observation its state is not the same as at the beginning. The recognition of this fact has shown the existence of a hitherto unsuspected subjective element in observation, and has caused a revision of the philosophy of physical science.

The late Professor Joly describes the brilliant theory of the revolutions in the earth's crust to which he made such large contributions. He shows that the earth's crust has, as it were, a 'life.' It is in continual movement and passes through a cycle of changes, each of which occupies tens of millions of years. The great geological revolutions correspond to the periods of mountain building in the earth's history. The existence of these epochs of mountain building is well established by the presence of the newer mountain ranges such as the Alps and Himalayas, and by the worn stumps of ancient ranges exhibited, for example, in the Killarney hills. What is the explanation of the origin of these revolutions? Professor Joly found it in the radioactive substances in the material of the earth's crust. Their presence causes the earth to accumulate heat, in spite of the escape of heat by radiation from its surface into space. The heat accumulates steadily through an epoch of tens of millions of years until it causes catastrophic changes in the structure of the earth's crust.

Professor Herbert Dingle analyzes the methods of astronomy in order to elucidate the proportions of fact and

fiction in astronomical theories. The discoveries of modern astronomy have recast men's ideas concerning the universe in which they find themselves, and it is necessary to determine with what degree of finality the new picture of the universe is to be accepted. Analysis shows that the facts of astronomical observation are to be accepted with graduations of certainty from high to low, but that a considerable part of the facts have a high degree of certainty. The theories invented to explain the observations are mental constructions and are more susceptible to revision and variation. A new observation does not affect old observations, it is merely an additional piece of knowledge; whereas it may prompt the invention of a new world-picture. The classical example of this is the result of the Michelson-Morley experiment. The single new fact was an addition of but one new fact to the previous body of astronomical facts, but the world-picture prompted by it was profoundly different from that prompted by those previously known. The recognition of the large contribution of the human imagination to the construction of a picture of the universe made astronomers more modest in their pretensions. They realize that whatever grandeur belongs to the universe has been created by themselves, and they hesitate to proclaim it.

Professor George Birkhoff finds that the renewed interest in mathematics has been caused by research in physics and logic. The classical physicists attempted to picture to themselves the course of all physical phenomena. They were not happy until they could see in their mind's eye the sequences in the changes of a material body. Mathematics was used as a probe for discovering the parts of this picture. The discovery of the quantum of action has shown that it is impossible to imagine pictures of the most refined aspects of atomic behaviour. Mathematics is no longer merely a tool for drawing pictures which help to understand: it is the only mental weapon for interpreting the results of modern physical experiment. Its status is raised. The philosophical importance of mathematics was increased when Boole showed that logic is a sort of mathematics in which all quantities are zero or

unity. The increase in knowledge has caused man to feel that he is surrounded by abstractions. The intellectual edifices of philosophy and science appear to him too formidable. Mathematics is his chief weapon for subduing this strange environment, making it manageable, and allowing him to see through it to the fundamental permanences.

Professor Antonio Aliotta explains why the introduction of a dynamic principle is the main achievement of modern research in logic. The old logic described the relations of phenomena statically, so that the rational world appeared as a system of unchanging essences and laws. In this system no place was left for change, and history consequently became unintelligible. Modern logic attempts to envisage rationality in a manner consonant with the most concrete exigencies of history and the human will.

Professor Aliotta outlines his own philosophy of experimentalism. He considers that experiment should be the criterion of truth in philosophy as in science. But experiment as a test of truth is irreconcilable with the older criterion of truth which rested on correspondence with reality, because it implies an interference with reality. An experiment always makes something new. It is not merely a confirmation or denial of what was previously known or suspected, but a movement to a new region of deeper and more comprehensive intuitions. A dynamic theory of rationality is necessary to meet the dilemma of freedom and predestination which remains insoluble in the static mode of conceiving rationality.

The revered Professor Max Planck discusses the concept of causality in the light of the quantum theory which he founded. The discovery that action is not a continuous phenomenon, but can happen only in finite quantities, was the first break with the fundamental ideas of classical physics. The existence of finite quantities of action fixes a limit to the possible accuracy in measuring phenomena. Haisenberg has expressed this law in his principle of uncertainty, and many philosophers have supposed that the impossibility of exactly determining the position or motion of an electron implies that matter possesses a certain freedom of action. If the

future behaviour of an electron cannot exactly be calculated, not because of defects in apparatus, but in the nature of things, the law of causality no longer comprehensively applies to material bodies. Professor Planck minutely examines the implications of the limitation of the application of the law of causality to the behaviour of electrons, and discusses what relations, if any, it has to the free-will problem. He takes a central position between the determinists and indeterminists, and finds that determinism reigns in an ideal world which exists, but is not accessible to the human intellect.

Professor A. E. Heath in his essay on Philosophy and Contemporary in Science summarizes the effects of advance in physical and biological science on philosophical ideas. The movements noted in more detail in the previous essays are arranged so that the reader may receive a general impression of the influence of science on human ideas concerning nature and life. He prefers to name the synthetic summary of the effects of science 'synoptic science' rather than philosophy. He concludes that the changes in scientific ideas have been more disturbing to science than philosophy. The character of the concepts devised by scientists to explain the strange new facts discovered by physical research is not unfamiliar to philosophers. The new concepts are not as surprising as the long period science has succeeded in progressing without them.

Science has changed the temper rather than the content of philosophy. It has communicated to philosophy a more rigorous analytical technique and has diminished the construction of speculative synthetic systems. It is qualifying as the tested foundation for a more satisfying social order, and may be to a new and brighter era what belief in providence has been for the old.

J. G. C.

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HEREDITY AND HUMAN AFFAIRS

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THE scientific study of human inheritance is a very new department of knowledge. It need not surprise us that in some quarters comprehensive claims have been put forward on its behalf. One school of opinion holds out the promise that a deeper understanding of the laws of human inheritance can disclose a clue to the rise and fall of civilisation, and contends that such knowledge can provide the only basis for a substantial improvement in the common lot of mankind. The grounds for such assertions are open to many criticisms. The basic problem of social evolution is not pre-eminently the origin of new types of men and women in a slowly changing physiographical environment. First and foremost it concerns the generation of new modes of behaviour in a rapidly changing man-made environment. In this respect human society has no close parallel among social organisms. If the laws of its development are ever brought into direct relation with the behaviour of other organisms, the study of the central nervous system will have far more to contribute than the study of reproduction. The most formidable problems of contemporary society do not arise from limitations in the ability of men and women to command the resources of nature. They arise from imperfect co-ordination of human effort. Time will show whether human ingenuity can discover forms of organisation which will guarantee the continued development of a mechanical civilisation. If mankind with its present endowments lacks the capacity to do so, the application of genetic knowledge can only offer a very remote prospect of producing a race of people which will.

Man is the most teachable of all animals, above all an

animal with an unusually complex development of the investigatory reflexes, and the only animal with an elaborate system of communication through the medium of speech, which exercises a predominant influence upon his social relations. Because of this, human society is a unique biological phenomenon, with unique laws of evolution. It does not follow that biology has nothing to teach us about social evolution. It does not follow that history, the descriptive study of how human behaviour patterns change from one generation to another, must always remain a science isolated from the field of biological enquiry. It means that a biological interpretation of human society and of human history, in so far as it is possible to undertake such an interpretation, must widen its scope beyond the narrow boundaries enclosed by the study of human inheritance to include everything we can find out about the physiology of speech, of learning, of hand and eye co-ordination and a host of kindred topics which are concerned with the specific characteristics of Man as a vertebrate, and with the fact that human societies differ from the most complex communities of social insects in their pre-eminently dynamic character.

At present those who study inheritance fraternise but seldom with nerve physiologists. In the past genetical discussion of questions touching upon their common field of interest has been very largely influenced by the teachings of the instinct psychologists of a bygone generation. For this reason many speculations upon social evolution prompted by the influence of the natural selection theory in its earlier phase must now be re-examined in the light of modern work on the central nervous system, as well as from the genetical standpoint. The study of behaviour in the lower animals reveals the existence of many simple reflex patterns which are consistent with a very wide range of external conditions. What has emerged pre-eminently from modern work such as that of Pavlov's school is that the relevant environment in which the behaviour patterns of the higher animals arise is not a fixed and static, but a dynamic and ever-changing pattern of stimuli; that this ever-changing pattern of stimuli

generates new patterns of conditioned reflexes and that the chronological no less than the spatial relations of the stimuli themselves are significant in producing such new patterns. This leaves the way open to the recognition that human society is a phenonemon *sui generis*, a phenomenon which owes its uniquely dynamic character to human inventiveness and the capacity of the human species to capitalize the fruits of its tool-bearing pursuits for the use of future generations through the medium of speech and its substitutes. Whatever differences of inborn constitution distinguish individuals and groups of individuals living in different places at different periods, the outstanding biological peculiarity of Man is the fact that an *infinitude of different behaviour patterns is consistent with the same genetic basis.* The instinct psychology of the selectionist school encouraged the belief that the student of human genetics would be able to detect simple unit characters in the domain of social behaviour. What we now know about the physiology of the nervous system does not encourage such a hope.

Extravagant assurances put forward by writers of the racialist school do not alter the fact that human genetics has a genuine claim to be encouraged as a branch of medicine. Research upon cancer has very little contribution to make to a scientific treatment of human history or to the removal of war, unemployment, and other evils which threaten the stability of existing civilisation. None the less, it is a field of investigation which rightly engages public esteem. Whatever else it may accomplish, genetic science can teach us much about the factors which determine susceptibility to disease for which curative measures are not yet available. It may thus be applied to the prevention of diseases for which there is no simple remedy. Of itself it is not a panacea for human ailments. It is an essential ingredient of the kind of knowledge upon which scientific prognosis must rest. Knowledge of this kind is not easy to gain. Special methods are necessary because of the intrinsic difficulty of dealing with a species which breeds slowly, has few offspring, and cannot be mated by the investigator at will. During the past two or three

decades great progress has been made in devising such methods. The results achieved have a real, if modest, claim to be considered as contributions to preventive medicine. It is in the field of preventive medicine rather than in relation to any of the great social issues of our time that the application of knowledge of human inheritance lies.

Physicians and their patients often ask the biologist whether tuberculous people should marry and have children, or whether mental diseases are inherited. Questions of this kind need to be stated in precise terms before it is possible to find a precise answer to them. The difficulty of making them sufficiently precise is partly due to the fact that the terms in which the problem of nature and nurture is discussed are very largely drawn from everyday speech. An anecdote in a recent biography of Mendel illustrates this well. In the year 1910 a memorial was being erected to honour Mendel in the place where he had spent his life teaching and had carried out his experimental researches. Among the citizens there was much talk of the distinction which Mendel's discoveries reflected upon the town. Two visitors were gazing at a portrait of the Abbé displayed in a shop window. One asked, "Do you know who this fellow Mendel was?" "Why, yes," was the reply; "he gave Brünn a bequeathing (*Vererbung*)." It has taken people a long while to outgrow this confusion between legal inheritance and biological inheritance. When Darwin wrote the *Origin of Species* the phenomena of fertilisation had not been directly observed in any animal. Biologists still believed that people hand on their noses to their offspring in much the same way as they hand on their bank balances. Even now there are a few biologists of an older generation who find the prospect of a hundred-per-cent. death duty equally repugnant, whether it is applied to their bank balances or to their noses. Weismann performed a great service to biology by pointing out that the state of death claims all our accumulated anatomical earnings. Our parents do not endow us with what Darwinian biologists called "characters." They endow us with *genes*. The genes cannot carry their cheque-books into the next life.

The modern term *gene* corresponds to what Mendel called "factors." The gene is the atom of hereditary transmission. It has the same logical status in genetics as the atom of chemistry. Like the atom, it cannot be seen. We infer its existence from two laws of experimental breeding analogous to two generalisations which led to the atomic theory of matter. One may be called the law of the conservation of hereditary matter. That is to say, it is always possible with sufficient trouble after a certain number of generations to recover individuals with the same hereditary equipment as the original parents of a cross between two varieties of animals or plants. The other might be called the law of the constancy of genetic proportions. In crosses between two races the proportions of the various types which appear in ensuing generations are numerically predictable.

In one respect the geneticist is more fortunate than the chemist. The larger units of physical chemistry formed by the combination of atoms are not individually recognisable. We have to infer the existence of molecules, like that of atoms, by indirect methods. Genes are built up into larger units called chromosomes, which we can actually see with the help of a powerful microscope. The number of chromosomes is the same in every one of the microscopic bricks, or *cells*, of our bodies. In Man the number is forty-eight. In both sexes we can distinguish twenty-three pairs, the two members of which are of the same size and shape. In the female the two members of the additional pair are of the same size and shape. In the male this pair is unequally mated. One member called the X (or sex) chromosome is of the same shape and size as the two equal elements XX of the corresponding pair in the female. The other, called the Y chromosome, is much smaller.

Man, like every other animal, begins his life as a single cell which divides repeatedly. This single cell, the fertilised egg, is formed by the union of the egg contributed by the mother, a cell just large enough to be seen by the eye, and a single microscopic cell of the seminal fluid. These cells or sperms are so minute that a large drop of seminal fluid contains

enough to produce all the human beings in the United States, if each sperm fertilised a different egg. The fertilised egg contains a double set of chromosomes, one member of each pair of the same size and shape being contributed by the egg, the other by the sperm. In the repeated cell divisions which occur throughout development each cell gets a representative of each chromosome in the fertilised egg, because the chromosomes themselves divide equally. An unusual type of division occurs in the formation of sperms and eggs. Each gamete (sperm or egg) gets only one representative of each pair of chromosomes, either a descendant of the one contributed by the father or a descendant of the one contributed by the mother.

This peculiarity of chromosome behaviour provides a clue to the laws which the Abbé Mendel discovered at the time when Darwin was writing the *Origin of Species*. The material basis of these laws was not discovered till forty years later. Today the behaviour of the chromosomes gives us a faithful picture of the way in which characters distinguishing different varieties stick together in hybrid experiments and also the way in which they are distributed among the sexes. Females are formed when a sperm with an X chromosome fertilises an egg, males when a sperm with a Y chromosome fertilises an egg. This explains why in crossing some varieties the male offspring do not share the characteristics of the father when the female offspring do so. Differences between varieties of this type are due to the genes of the X chromosomes.

The sperm and the egg are the only link between two generations common to all animals. We might define a difference due to heredity, or, as it is better to say, a *genetic* difference, between two individuals as a difference which has its basis in a different structure or material composition of the gametes at the time of fertilisation. A difference due to environment would then be a difference due to any dissimilarities in the infinite number of agencies with which the fertilised egg reacts in the course of its development or in the subsequent life history of the fully developed human being.

Environment as it is thus interpreted by the biologist includes the influence of maternal circulation and health on the offspring between fertilisation and birth. A distinction framed in this way has useful theoretical implications. It does not help us to distinguish between differences due to environment and differences due to heredity, when we actually see them as end products in the development of two human beings. Before we can ask the right sort of questions about the inheritance of diseases, or, to be more exact, the inheritance of gene differences which affect the liability to contract a disease, we must pause to clarify the distinction by examples which occur in the practice of breeding.

If chickens are fed on yellow corn or given green food, we can distinguish between some varieties which breed true for yellow shanks and others which breed true for colourless shanks. This is a *genetic difference.* When all the progeny are fed on yellow corn or given green food, crosses between such varieties yield numerical ratios of the two types in conformity with Mendel's principle. If chicks of the variety with yellow shanks are fed exclusively on white corn they grow up with colourless shanks. The difference between a fowl of the yellow variety brought up on yellow corn and a fowl of the same variety brought up on white corn is a *difference due to environment.* If we were to cross fowls of the yellow variety with fowls of other varieties, giving some of the progeny yellow corn and others white corn, we should not expect to obtain constant numerical ratios such as Mendel's principle predicts. Let us suppose that two poultry farms, both using yellow corn for food, specialised respectively on birds with black plumage and yellow shanks and birds with barred plumage and white shanks. We should call both differences genetic differences. If both farms decided to use white corn, we should only be able to recognise the plumage difference as a genetic difference. If both farms varied their procedure from week to week, we should not be able to tell whether the difference between one bird with yellow shanks and another bird with colourless shanks was a genetic difference or a difference due to environment.

Another example may help to make the distinction more clear. Some rabbits deposit yellow fat when fed on green-stuffs. Most rabbits have white fat, whether given greens with their food or not. Yellow fat is a serious carcase defect from a business point of view, because purchasers object to it. Rabbits which have white fat when fed on green food possess a liver ferment which breaks down the yellow pigment in plants, thus preventing it from reaching the fat deposits. Rabbits which deposit yellow fat lack this enzyme. It has been shown that when rabbits of both kinds are crossed and backward crossed, the absence of the ferment behaves like an ordinary "recessive character" (*vide infra*). It is only recognisable as such if the rabbits are given green food containing the yellow pigment. In a group of rabbits of both types we can recognise the gene difference by giving them all green food. If we do so the biological environment is *neutral* in Professor Levy's sense,[1] and the gene difference is what he calls *isolate*, which we are investigating. If we have a group of rabbits none of which possesses the enzyme which breaks down the yellow pigment, we can make their fat white by feeding them on mash and potatoes, or yellow by feeding them on mash and cabbage. In that situation the genetic constitution is neutral, and the biological environment is the isolate of the investigation. The practical breeder has two remedies from which he can choose. He may either put the blame upon the biological environment and cut off the supply of green food, or he may put the blame upon heredity and breed for white fat.

Sometimes the doctor can put the blame on heredity and at others upon environment for the manifestation of one and the same clinical phenomenon. A biological parallel to a small class included under the general term "idiots" illustrates this very clearly. *Cretinism* is due to insufficient quantity of the iodine compound manufactured by the thyroid gland. Insufficiency of the same hormone in frogs, toads and salamanders prevents the aquatic tadpole from

[1] H. Levy, *The Universe of Science.*

transforming into the terrestrial adult. This may be because the thyroid gland is incapable of doing its proper work. Even when it can do so, it is unable to make thyroxine without iodine. So if tadpoles are kept in water with no trace of iodine and fed upon a diet free of iodine compounds, they fail to transform into frogs. European newts normally complete their development and breed in the adult form. In certain mountainous districts where *endemic* cretinism is reported among human beings, the newts commonly fail to undergo metamorphosis, or do so after a long delay. This is probably because the iodine content of the waters in which they live is low. A similar explanation does not apply to a local race of the American newt (*Ambystoma tigrinum*) which lives in lakes in the neighbourhood of Mexico City. Individuals belonging to this race never grow up; they breed from generation to generation in the aquatic form. They will grow into the terrestrial newt if fed on thyroid gland. They will not do so if given iodine compounds. They possess a thyroid gland which does not release its secretion into the circulation. The Mexican variety breeds true for its inability to undergo metamorphosis when kept in aquaria with access to an abundance of iodine compounds.

If we compare human birth with the emergence of the aquatic larva upon dry land, insufficient thyroid secretion in the maternal circulation corresponds to keeping tadpoles in a tank with iodine-free water and food containing no iodine compounds. In many discussions of mental inheritance the term *environment* is inaccurately equated to training, and even to training at so late a stage as when school education begins. This is very misleading. The fact that a condition is congenital provides no presumptive evidence for the view that environment is of little ætiological significance. It is equally compatible with the belief that genetic differences account for its occurrence, that it is determined by idiosyncrasies of the uterine environment, or that both these agencies play their part in its manifestation. Several classes of facts point to the importance of exploring the influence of the uterine environment upon the characteristics of individuals. One is

the high incidence of certain conditions among first-born children. Another is the high incidence of various malformations among offspring of women approaching the end of the child-bearing period.

When a contrast was drawn between variations in plumage colour and the colour of the shanks, we did not separate a class of phenomena to which the Mendelian principle applies from a class of phenomena to which it does not apply. The object was to distinguish between a class of phenomena which are easy to study and a class of phenomena which demand more care in controlling the environment. There is no hard-and-fast line between the two. Genetic differences which distinguish plumage colour in fowls are recognisable over a very wide range of environment. This does not mean that they are just as big in every environment which human ingenuity can devise. The difference between the black plumage of an Ancona and the mottled plumage of the Light Sussex is a genetic difference. By adding thyroid extracts to the food the extent of the black areas in the Light Sussex can be very considerably extended.

No statement about a genetic difference has any scientific meaning unless it includes or implies a specification of the environment in which it manifests itself in a particular manner. Characteristics of organisms are the result of interaction between a certain genetic equipment inherent in the fertilised egg and a certain configuration of extrinsic agencies which in the case of human beings include the conditions of life in the uterus as well as the external environment in which social existence is carried on. Differences between individuals may arise from differences in the kind of genes present in the fertilised egg and from differences in the uterine or post-natal environment. Differences due to a difference of genes may be of two types: (1) differences which are recognisable in almost any environment in which the fertilised egg will develop and continue to grow; and (2) differences which are only manifest within a restricted range of environment. Examples of the first are the difference between a "hæmophiliac" and an adult whose blood coagulates in the normal

way, or between an amaurotic family idiot and healthy infant. An example of the second type is furnished by the type of mental defective known as the "mongol." Whatever gene differences are involved in this condition appear to require a special pre-natal environment to make them recognisable.

The distinction between these two classes is of the utmost importance from a preventive point of view. When we have to deal with the first we can readily determine the type of transmission involved. On the basis of Professor J. B. S. Haldane's analysis of genetic selection, in a series of brilliant memoirs dealing with the mathematical developments of modern genetics, we can predict with some confidence the rate at which affected individuals can be eliminated by any type of interference with parenthood. When we encounter the second it is more difficult to determine the method of transmission. Unless affected individuals are extremely rare, it is generally impossible to do so, until we can specify with some precision the sort of environment in which they are recognisable. Thus we cannot give a certain answer to the question, what would be the result of selective interference with parenthood? Usually we could deal with the matter without recourse to selection, if we had the kind of knowledge which enables us to say how much reduction selection would bring about. For instance, we know sufficient today about the way in which people get cholera to study the genes involved in susceptibility to the disease among a group of individuals equally exposed to the danger of contracting it. The fact that we have the knowledge to study the problem is the reason why it is of no practical importance to do so. To understand the environmental situation is to be able to control it.

We may express this important truth in another way. When we understand the *modus operandi* of the gene, we can state the kind of knowledge we need in order to control the conditions in which its presence will be recognised. As J. G. Crowther has remarked, pioneers of the evolutionary theory, being preoccupied with the shapes of animals, handed on the same obsession to the earlier geneticists. Out of it grew

the belief that artificial selection is the only remedy when once we have put the blame upon heredity. Though we still believe that selection has its uses, biologists are becoming more critical towards the ultra-calvinistic attitude of Galton and his disciples. This is because the geneticist has begun to deal with the gene as a reagent in the process of development. The study of gene differences is becoming part of the dynamics of the organism. If we are content to endow a gene with the property of making urine black, the outlook for the individual patient is also black. Selection is, then, the only remedy for the condition known as "alcaptonuria." If we envisage the gene displaced as the precursor of an enzyme which completes the breakdown of the meat in our food, we discern alternative possibilities. Biochemical discovery may one day make the missing ingredient available for individual use. Recent work on œstrin therapy for hæmophilia shows that such a possibility is not an idle dream. The blood of hæmophiliacs fails to clot, so that they die very often of hæmorrhage. Only males suffer from the disease. The gene responsible cannot manifest its effect in the biochemical environment of a female body. Males may be cured by giving them the female sex hormone.

A variety of the domestic fowl known as the Frizzle helps us to adopt a new perspective. It has defective plumage. Frizzle crossbreds are distinguished by curling of the feathers upwards and outwards. The pure-bred Frizzle remains practically bare throughout its first year of life. It appears to be in a state of perpetual moulting. It is extremely delicate and difficult to rear. When newly hatched, the down feathering is fragile and easily breaks off. The exposure of the skin so produced leads to a great loss of bodily heat from the surface. This calls forth increased basal metabolism, increased heat production, increased heart-rate, lack of fat deposits, and diminished hæmoglobin content of the blood. It has now been shown that the pure Frizzle chick will develop within three weeks a complete plumage over the whole body if protected from heat loss by enclosure in a woollen jacket and confined to a warm room. Knowledge of the way in which a

single gene difference produces its deleterious manifestations thus teaches us how to prevent their appearance.

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Having cleared the ground of erroneous and antiquated notions about heredity and environment, we are now in a position to see what sort of questions we can intelligibly ask about the rôle of heredity in disease. One is whether liability to suffer from any particular disease is associated with gene differences. Another is whether such gene differences are of the kind which would be apparent throughout a range of environment as great as that to which members of the same fraternity, stock, or social group are exposed. We now possess methods which enable us to detect gene differences which are recognisable throughout a wide range of human environment and differences which are not. Naturally, we know most about the first kind, since they are simpler to deal with. All the best examples are derived from the study of what medical authorities call "hereditary" and "familial" diseases of the body.

When we are studying inheritance in human beings it is not possible to start with pure-bred stocks. Hence if a human trait is recessive—that is to say, if it is only manifest when the individual receives a particular gene from both parents—a certain proportion of individuals who do not manifest the same trait receive the gene from one but not from the other parent. If a trait is dominant—that is to say, if it is recognisable when the individual who shows it receives a particular gene from one parent only—it may not be possible to tell from the appearance of any given individual whether he or she has received it from one or both parents. To establish quantitative laws of human inheritance it is necessary to know what proportions of people receive a given gene from one and what proportion from both parents. Marriage is a lottery. The natural history of lotteries, or, as we more usually call it, the theory of algebraic probability, enables us to tell what proportion of individuals will derive a given gene from both parents or from one parent only, if we know the propor-

tion who do not possess it. Thus the net expectation for different kinds of offspring of parents of a specified type can easily be calculated if mating occurs at random. Mating does not always occur strictly at random in human communities. A talented contemporary authoress has reminded us that gentlemen prefer blondes. Allowance can be made for this by studying the correlation between husbands and wives.

When the possession of a physical trait does not appreciably affect the choice of a mate, it is easily shown that the number of individuals who carry a rare gene on one chromosome but not on its fellow is twice the square root of the number who carry it on both members of the same pair of chromosomes. The meaning of this statement may be illustrated by albinism. Albinism is a recessive condition. In this country the proportion of albinos in the community is about one in twenty thousand. According to the principle of random mating, one in every seventy individuals who are not albinos should therefore carry the gene for albinism on one of their chromosomes. Individuals who display a very rare dominant condition will nearly always possess the gene which determines it on one chromosome only. Half the offspring of such individuals, if married to a normal person, should have the dominant trait. This is easy to test in the numerous pedigrees of what medical men refer to as "hereditary" diseases or disfigurements. Such are brachydactyly, a congenital absence of one of the joints of the fingers, one form of night blindness, a somewhat repulsive abnormality known as lobster claw which is a deformity of the lower limb, the disease known as diabetes insipidus, distinguished by excessive passing of urine, Huntingdon's chorea, a disease with some resemblance to St. Vitus's dance, and a defect of the pupil called aniridia. These conform in a satisfactory way to the numerical requirements of Mendel's law. Except in so far as the supply is replenished by fresh sports (or "mutations"), they could be eliminated in a generation if individuals suffering from them were not allowed to reproduce. When diseases of this class are incurable, this is the only effective method of prevention known at present.

At first it seemed more difficult to identify recessive genes in human beings. An individual who exhibits a recessive condition must receive the gene from both parents, and may thus be the offspring of one of three types of marriage: a marriage between two recessives; a marriage between a recessive and an apparently normal individual who carries the gene; or a marriage between two carriers neither of whom exhibit the trait. What has been said about albinism shows that marriages of the last type will be much more common than the other two, since carriers are so much more common than albinos. So recessives are generally offspring of parents who are not themselves recessives and have no near ancestors who are recessives. They are not detected by collecting long pedigrees. The principles of animal and plant breeding tell us that if two parents are carriers one-quarter of their offspring will be recessives. Thus recessive conditions tend to turn up among several brothers and sisters in a family. In the language of the medical profession, they are "familial." The proportion predicted by genetic theory is easily tested by collecting sufficient cases.

A second criterion is still more valuable, especially if the recognition of a recessive gene substitution depends on conditions which are not always present in the family environment. Consanguineous parentage will always be noticeably more common among parents of rare recessives than among the general population. The proportion of consanguineous parentage can be stated precisely as a function of the rarity of the recessive condition. About 15 per cent. of the parents of children who die of the wasting disease called amaurotic family idiocy and about 10 per cent. of deaf mutes are first cousins. The percentage of all marriages between first cousins in the population at large generally varies between ½ and 1 per cent. in European communities. Without introducing mathematical symbols, the reason for this is easy to grasp, though unaided common sense is not sufficient to tell us how rare a recessive condition must be if we are to detect a large enough excess of consanguineous parentage. If I carry the gene for albinism on one of my chromosomes, the chance

that I shall marry an unrelated individual who is likewise a carrier is only one in seventy. If I marry my cousin, I am marrying an individual who has received a certain proportion of her chromosomes from the same pair of grandparents as myself. The chance that the offspring of two grandparents will both receive a particular chromosome from one of them is one in eight. So, if I am myself a carrier, the odds that I should marry another carrier would be nearly ten times greater than if I married someone who was not related to me.

About a dozen of these recessive conditions are now well established. One is a type of partial blindness known as retinitis pigmentosa. Amaurotic family idiocy and juvenile amaurotic idiocy are two other examples. These diseases, which involve progressive blindness, dementia, and wasting, are fatal, one at about two, the other at about sixteen years. If two parents produce an amaurotic child, the odds are that one-half of their offspring will carry the gene, and one-quarter will exhibit it. It is difficult to justify the English law which does not permit such parents to avail themselves of a very simple operation to prevent the further spread of the unwelcome genes which are responsible for these two formidable and at present quite incurable diseases. Sterilisation of the individuals directly affected is in this case undertaken by nature, since individuals die before they can propagate their kind. It is an important fact that selection eliminates recessive conditions very slowly. If all albinos were sterilised in every generation it would take many centuries to reduce the incidence of albinism to half its present dimensions. Research upon the characteristics of individuals of consanguineous parentage is likely to increase our knowledge of recessive genes in the human species considerably. At present a larger number of dominant than of recessive sports or "mutants" are known to exist among human beings. This is contrary to what occurs in most wild animals. In nature dominant mutations seem to be rare. Probably there are more recessive than dominant mutations in Man. The apparent rarity of recessive mutations may be due to the fact that the method of detecting them has only been recently perfected. This is

supported by the existence of one special class of recessive genes not included in what has been said hitherto. Recessive genes which make up the X chromosomes are easily recognised by the fact that recessive females are much rarer than recessive males. Red-green colour blindness is a case of this type of inheritance. Colour-blind males are at least ten times as common as colour-blind females.

Recessive genes known to be in the X chromosomes are more numerous than all the recessive genes at present known to be located on the remaining twenty-three pairs of human chromosomes. No doubt this is because the peculiar type of inheritance to which they give rise attracted medical interest more than a century ago in connection with the study of hæmophilia. There is a strain of hæmophilia in the Royal Houses of Europe. This leads us to ask whether a sterilisation policy would raise the standard of physical fitness among Royalty. It has been said that the sterilisation of individuals who display recessive conditions of the ordinary type produces very little effect because the genes are principally transmitted by individuals who do not exhibit the recessive condition. This does not apply to conditions due to X-borne recessive genes. Since the male has only one sex chromosome, all males who carry the recessive gene exhibit the recessive trait, unless special conditions of environment are essential to its manifestation. Sterilisation of all individuals displaying "sex-linked" recessive diseases halves the proportion of persons affected in every generation.

The tendency of traits to stick together has made it possible to construct maps of the chromosomes in animals and plants. All the known genes of the fruit fly and the sweet pea can be assigned to their respective chromosomes and to a particular position relative to other genes on the same chromosomes as themselves. The genes whose manifest effects are easy to distinguish in human beings are mostly rare. It is therefore exceedingly unlikely that we should encounter two in the same pedigree. For this reason the possibility of constructing a chromosome map of the human species seemed quite fantastic ten years ago. Today the prospects are very

hopeful. The possibility of doing so has emerged from the study of the blood groups.

People can be classified in four groups according to whether the blood of one individual when mixed with another curdles. The four blood groups depend upon three genes, one group being recessive, one group depending on the presence of one dominant gene, a third on the presence of another dominant gene, and the fourth on the presence of both dominant genes. The two dominant genes have arisen by mutation from one and the same recessive gene. They cannot both be present on one and the same chromosome. Population studies on hundreds of thousands of individuals have shown that the different proportions of these groups in different communities correspond to the requirements of the theory of random mating with extraordinary fidelity. Parents and offspring of more than five thousand families have been systematically examined. The results are in close agreement with what would be predicted, if the explanation already given is the correct one. Their importance for the study of human inheritance resides in the fact that the frequency with which the three blood-group genes occur in the general population is much the same. Hence it is easy to test whether they tend to stick together with other genes.

If blood-group testing were carried out in all records of hospital pedigrees, it would be possible to ascertain whether rare genes responsible for diseases like amaurotic idiocy or night blindness reside on the same chromosomes as the three genes of the blood groups. Blood-curdling can also be produced by injecting sera of other animals into the circulation. People have now been classified for their reactions to various "foreign" sera. Other blood groupings of similar proportions have been based on such reactions, and the transmission of at least one such series has been worked out. It has been shown that the genes involved are not located on the same pair of chromosomes as the three genes of the Jansky blood groups. It is not unlikely that we shall soon be able to test for a blood grouping referable to every one of the twenty-four pairs of human chromosomes. Recently it has been shown

that about a quarter of the population are incapable of tasting a group of substances allied to and including the organic compound called phenyl-thiourea. This substance is described as exceedingly bitter by those who can taste it. Ability to taste is determined by a single dominant gene. About as many people have the dominant gene as lack it. Like the blood-group test, "taste blindness" may play a part in the mapping of the human chromosomes.

About thirty known incurable diseases are determined by genes whose existence is established by agreement with the numerical requirements of Mendel's laws. This list includes several forms of blindness. It does not include a long list of presumptive cases which will probably be added in the near future. We do not yet know of any enviable characteristics of human beings determined by single genes. Even the inheritance of the platinum blonde is still a topic for future research. The next few years will probably witness very rapid progress in establishing precise laws of hereditary transmission for physical traits which are little affected by the differences of environment to which different human beings belonging to the same pedigree are ordinarily exposed.

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So far our examples of well-established genetic differences between human beings have been taken from the field of medicine. There are other physical differences determined by genes, such as those which distinguish people of one geographical variety or race from those of another. Differences of hair colour, eye colour, nose breadth, the curliness of the hair, stature, and the like, are true genetic differences, though we do not know very much about the genes which affect them. In most cases such differences appear to involve many genes, and further analysis of the way in which they are inherited defies the methods at present available. Thus the difference of skin colour between a negro and European must involve at least four and probably more gene differences. Such differences are much less interesting to the student of

human affairs than are differences of temperament and culture. Many writers on heredity and human affairs succumb to the temptation of assuming that such differences like physical idiosyncrasies used to classify mankind in races are mainly due to different combinations of genes. When they do so they are not speaking as biologists. Biology can as yet tell us little about how such differences arise.

At the same time it is natural and proper to ask whether gene differences can affect social behaviour. Social behaviour has its material basis in the structure and functional activity of the central nervous system. It would be surprising if there were no individual differences in the function and structure of the nervous system due to different combinations of genes. Such differences can be studied experimentally in animals. For instance, sports of the fruit fly can be distinguished by their reaction to light. Some strains of rats learn to thread mazes more readily than others. Extreme disorders of the central nervous system accompanied by extreme aberrations of social behaviour are known to be determined by gene differences in human beings. Amaurotic family idiocy is an example which is very firmly established.

Studies on genetic differences which affect the social behaviour of human beings are beset by two principal difficulties. Social behaviour depends upon a long process of training which does not begin until physical differentiation is well-nigh complete. Even the grosser abnormalities described under the general term *amentia*, or mental defect, are not always recognisable till several years after birth. Hence we have to exercise great care in deciding how far the manifestation of genes involved in such conditions depends upon factors of early development. Another difficulty resides in the lack of precise and reliable standards for describing social behaviour within the range of what we regard as normal.

A beginning has been made with the intelligence tests of Binet, Terman, Burt, Spearman, and others. When people apply the word "intelligent" to a person, they do not mean something as definite as black, freckled, or intoxicated. We may even ask whether any useful meaning can be attached

to the word as a description of the characteristics of human beings. The only way to answer such a question is to let different observers arrange a group of individuals in a scale of what they call greater or less intelligence, and to see how far it is possible to devise some independent test by which the same group can be arranged in a way which corresponds fairly closely with independent estimates based on personal impressions. This is what an intelligence test does.

Those who are not conversant with the problem often assert that intelligence tests do not really measure intelligence. This is a survival of the scholastic delusion that words are more real than the functions they perform in social intercourse. It would be more true to say that the only precise meaning of the word "intelligence" is conveyed by whatever characteristic intelligence tests measure. In everyday speech the word "intelligence" is used in a variety of ways. Dean Inge might describe a social policy as intelligent. In that case I myself should probably describe it as unintelligent. An intelligence test does not measure anything which we mean by the word "intelligence" in that context. In matters affecting moral or æsthetic values Dean Inge and I would commonly use the word in exactly the opposite sense. In spite of this, both of us sometimes use the word to draw attention to characteristics of human behaviour quite as definite as freckles or alcoholic excitement. Our description of such characteristics need not be affected by our social prejudices more than counting the number of pages in a book. It is the essence of the modern scientific outlook that genuine scientific knowledge involves the construction of a world of public discourse which is ethically neutral in this sense. A large amount of very careful statistical analysis has been directed to find a scale which will absorb everything which is public in the ways in which people use the word "intelligent" individually. The tests on which this scale is based yield very constant results for the same individual examined on successive occasions with a short intervening period, and very constant results for the order within a group tested successively over a period of several years.

Dubious speculations psychologists may erect upon this solid foundation of fact need not concern us. We have now a method of describing one aspect of human behaviour with precision and reliability. It is a method which can be passed from the hands of one observer to another. We can pool the results of intelligence tests. This we could not do if we had to rely on any customary scale such as teachers' estimates, examination results, or employers' testimonials. So the biologist can investigate to what extent differences of intelligence are due to the fact that different children are born with different genes, and to what extent they are due to the fact that the genes manifest their effects in different surroundings determined by maternal health in prenatal existence, a poorly nourished body, over-indulgent parents, overbearing brothers and sisters, sympathetic teachers, and an infinite variety of other circumstances which distinguish the physical or social environment of one individual from that of another.

Unless, as is never the case with human beings, two parents are both strictly pure in the genetic sense, their offspring will get a different equipment of genes. This is because any chromosome which a child gets from one of its parents may either be the chromosome which that parent received from its male or the one it received from its female parent. The surroundings of two brothers and sisters brought up in the same family are more alike than those of two children belonging to different families at different social levels. It is therefore necessary to distinguish two problems which are often confused. One is how much differences within the family are affected by differences due to genes and differences due to environment. The other is how much differences between individuals in different social groups, such as classes or races, are due to one or the other. The first question can be answered with some assurance. When there are no differences due to genes, the average difference between brothers or sisters is not reduced by more than a half.

This conclusion rests upon very careful statistical comparison of the resemblance between identical twins and non-identical twins of the same sex. More than five hundred pairs

of each type have been examined with intelligence tests. The investigations have been carried out in several countries, and they lead to substantially similar results. The test scores of identical twins which are derived from the same fertilised egg and therefore have the same genes yield an average difference about half as large as that of fraternal twins, who are not more alike genetically than ordinary brothers and sisters. The figure given is probably a minimum estimate of the influence of nurture for a reason suggested by the biblical narrative. Esau and Jacob are described as being physically different. One took to the fields, the other dwelt in tents. To some extent individual human beings select their own surroundings like Jacob and Esau. It is not fair to assume that the environment of fraternal twins differs as little as that of identical twins. Being more alike in other respects, identical twins are more likely to choose more similar surroundings, play together, work together, and be exposed to the same sources of infection. Hence a part of the greater difference between fraternal twins may be due to the fact that their upbringing is less alike, when there are considerable physical differences between them. Another reason why the estimate given is likely to exaggerate the genetic contribution to differences of intelligence within the family is that fraternal twins are more alike than ordinary brothers and sisters. Different birth rank accounts for appreciable differences of intelligence within the family.

Between birth and the age at which formal education begins there exists a protracted and, it may be, highly significant period during which differences of social environment may affect the behaviour of an individual. Hence the comparative constancy of a psychological index such as the Intelligence Quotient between four and fourteen years of age offers no presupposition in favour of the view that it measures a characteristic which is little affected by differences in the family environment. While relying too largely on introspective methods and concepts of questionable validity, the Freudian school have performed a service to human biology by focussing attention on the importance of the social en-

vironment during the years when the basic patterns of conditioned behaviour are established.

This leads us to the second question. How far do genetic differences contribute to differences between individuals belonging to different social groups? Various racial and occupational inquiries have been carried out. The conclusions drawn from them have rarely been warranted by the facts. Both in England and America the average scores hitherto recorded for the children of the unskilled workers are somewhat smaller than for the children of the professional class. The difference is not greater than variations which the individual index or intelligence quotient may register in the lifetime of an individual or variations associated with different birth rank in the same family. If differences of environment account for a substantial fraction of the average difference between brothers and sisters brought up together in the same family, it would not be surprising to find substantial average differences between groups of people living in very different conditions. The differences which are found are rather smaller than one might well expect without assuming that there exists much heterogeneity in the distribution of genes affecting intelligence. The few studies made upon orphan children are based on insufficient numbers to prove much. All the racial studies which have been undertaken so far have been highly selective.

It is easy to maintain scientific accuracy in making observations upon race differences. It is difficult to exclude social prejudices from the interpretation of the data. This is too well illustrated by the numerous and discordant comparisons which have been made between negroes and white Americans. Davenport and Steggerda, who made a comparison between negroes, white settlers, and hybrids in Jamaica, where the two races live together in comparative harmony, used the American Army tests. In one-half of these the negroes excelled. In the other the whites obtained higher scores. The negroes did best in the arithmetical tests, the whites in the verbal ones. This is how Davenport and Steggerda interpret their results. "The Blacks seem to do better in simple mental arithmetic,

and with numerical series than the Whites. . . . It seems a plausible hypothesis, for which there is considerable support, that the more complicated a brain, the more numerous its association fibres, the less satisfactorily it performs the simple numerical problems which a calculating machine does so quickly and accurately." Experimental biologists will be interested to learn that anatomists have located the basis of mathematical operations with such precision. The casual reader may wonder why Davenport and his colleague went to the trouble of applying these tests, if they had satisfied themselves that the large mass of evidence pointing to a high correlation between verbal and numerical test scores rests upon a misunderstanding which they do not disclose.

The difficulty of treating group differences in a genuinely scientific temper will be less, when psychology can equip biological research with a sufficient variety of similar methods for the precise description of other aspects of social behaviour. One can assert that deaf-mutism is commoner among Jews than among Gentiles without incurring the charge of anti-Semitism. With so many diagnosable physical ailments to choose from, it is possible for normal people to discuss the occupational or racial distribution of any single disease of the body without assuming a tone of impudent superiority; no single group has the monopoly of all the virtues. When we turn to what is written about the social capacities of men and women the atmosphere changes. Some biologists are apt to forget that it is quite possible that the distribution of genes among the Scotch tends to favour a rather higher general level of intelligence than would be found among negroes educated in the same way. One can be open to be convinced that this is so, and retain a personal preference for generosity, cheerfulness, a sense of humour, vocal music without the accompaniment of bagpipes, and the restraint which permits a man to listen to a joke without explaining the point of it to its inventor. Time may show that there are genes which have something to do with the distribution of all these estimable attributes. We shall then see the superior intelligence of the Scotch in a proper social perspective.

The characteristics which permit human beings to co-operate in creating a dynamic society are very numerous. In the past men as a group have monopolised those occupations which most conspicuously call for the exercise of intelligence. When women first demanded freedom to compete with them the bulk of educated male opinion was unanimous in asserting the inferiority of their intelligence as a group. Intelligence test statistics have now shown that there is no such sex difference. Individual women who wish to pursue a learned profession can now do so. The result of this does not appear to be that the proportion of men and women are tending to become the same in all occupations. Professor Tawney is a sound biologist when he asserts that equality of privilege is the best way to ensure that the individual differences of men and women will find appropriate recognition. We are only free to judge the innate capacities of men and women when they themselves are free to choose the kind of environment in which their capacities can be realised. To adjust the activities of individuals as far as possible to their inborn aptitudes it is necessary to establish a rationally planned economy with equality of social privileges and prestige pertaining to all necessary occupations, and so minimise the disposition to prefer the livelihood of an inefficient doctor to that of an expert plumber.

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The study of mental diseases—that is to say, disorders of social behaviour—invites examination from the standpoint of genetics just as much as diseases of the body. When a disease cannot be cured by controlling the environment, the only effective method of prevention is to prohibit the reproduction of persons who suffer from it and of parents who have already given birth to offspring who suffer from it. One class of disease which has prompted proposals for a preventive policy of this kind is feeble-mindedness. Amentia, to use the more general term which includes the lower grades of mental defect, is an exceedingly complex group of disorders. Some

forms are due to avoidable diseases in childhood, such as syphilis, encephalitis lethargica, and meningitis. Dr. Penrose, who has made a special study of the hereditary aspect of mental defect, estimates that about 12 per cent. of persons in institutions belong to this class. There is a type of amentia, known as mongolian idiocy, associated with certain physical traits to which the name is due. This seems to be due to a recessive gene which does not exercise any recognisable effect unless the unborn child is exposed to rather special conditions of prenatal environment. This is indicated by the fact that mongolian idiots usually occur at the end of a family, and are children of mothers who are approaching the limit of their child-bearing period. Mongols do not reproduce. The proportion born could be probably reduced to about a third of what it is now if child-bearing were restricted to the period between twenty-two and thirty-two years of age.

There is a large class of *amentia* which is not associated with diseases of childhood, and is not recognisable at birth by any physical stigmata. This includes the higher grades of feeble-mindedness. Feeble-mindedness is now defined with reference to the requirements of intelligence tests. Individuals are not certified as such unless they appear before the police court, apply for poor law relief, or are sent from the ordinary elementary schools to special institutions for retarded children. There is no means of estimating its prevalence among the prosperous classes, where eccentricity fades into the diplomatic service. At present we have very little knowledge about the part played by heredity in feeble-mindedness. Haldane's analysis has shown us that it is impossible to predict the results of checking the propagation of feeble-minded people until we know something more about the mode of transmission involved. It is clearly desirable to study the problem carefully, and to make the best of all the knowledge we gain.

When we are studying animals in the laboratory we can arrange the conditions of an experiment so as to isolate gene differences or differences due to environment for separate investigation. Using a highly inbred stock of rats, we can

examine the way in which body weight varies with the vitamin content of the food or whether they form tumours when the skin is treated with coal-tar derivatives. Keeping all our rats on the same diet, we can separate pure lines with different growth rates and greater or less resistance to tumours by selection from a heterogeneous stock. With human populations the unaided investigator cannot do this sort of thing. Curiously enough, those who call themselves eugenists, the English equivalent of Continental Fascists, and profess as such to be genuinely concerned with the promotion of more exact knowledge about human inheritance, are foremost in opposing social changes which would tend to equalise the human environment.

The human geneticist has to be content with recognising the kind of gene differences which manifest themselves over a wide range of environment and trying out certain algebraical predictions which show us how gene differences affect the variability of highly modifiable characteristics. If, having done so, we speak of heredity or environment as more or less *important* in connection with any differences between human beings, our criterion of importance is relative to the historic environment in which the differences themselves are measured. Two hundred years ago the majority of Englishmen ran the risk of smallpox infection. No doubt gene differences played a large part in deciding whether a particular Englishman succumbed to the disease or escaped. No biologist or medical man would argue that gene differences provide the main reason why modern Englishmen are less likely to get smallpox than were their great-grandfathers or than Esquimaux are at the present day.

That biologists do not always give the same answer to questions about heredity and feeble-mindedness is partly due to the fact that questions framed in everyday speech involve an ambiguity which arises from the changing nature of the human environment. If we ask, "Is amaurotic idiocy associated with a gene difference which manifests its presence throughout the whole range of conditions to which members of the same fraternity are normally exposed?" we can expect

a biological answer because we have framed the question in biological language. No biologist who is conversant with the facts will hesitate to answer the question in the affirmative. No sensible people who know the answer would encourage a married couple who had produced a child with the disease to have more children. If we ask, "Is feeble-mindedness inherited?" many biologists will answer in the affirmative. They will not do so because our knowledge about the gene differences which affect feeble-mindedness is of the same definite and unequivocal kind as our knowledge about amaurotic idiocy. They will interpret the question in a sociological sense, and give it what is implicitly a sociological answer. The underlying assumption is that if we cannot control the environment we ought to take no chances with the hereditary aspect of the problem. There is much to be said for this, providing it is not used as an excuse for relaxing our efforts to understand how to control the environment. In the course of millennia it is not unlikely that European communities could evolve a high degree of immunity to smallpox through uncontrolled selective elimination of the less resistant. The African peoples have probably evolved their high immunity to malaria in this way. Thanks to human inventiveness, we have not had to wait several millennia to get rid of smallpox.

There is no doubt about the concentration of mental defect of one kind or another in certain inbred stocks, and such concentration is not likely to be due entirely to the family environment. On the other hand, the fact that the family is a unit of social and physical environment, and that the ancestry of a human being is a complex of environmental as well as genealogical relationships, is entirely consistent with the view that genetic differences manifest in such pedigrees would not necessarily manifest themselves in other situations. About this biologists are of two persuasions. One school holds that the genetic difference is all-important and that the association of a hereditary taint with a depressed standard of life is due to social selection. Another school holds that a depressed standard of social and physical life is especially propitious to the exhibition of gene differences which might not

be recognisable in favourable surroundings. A danger ot over-emphasising the genetic aspect of mental defect in the present state of knowledge is that it will discourage research into the rôle of the environment and so deprive the human geneticist of information which is essential in making a confident estimate of what selection can achieve.

That we cannot point to any factors in the environment responsible for a disease or defect does not necessarily mean that it is associated with gene differences which manifest themselves throughout a wide range of environment, or that selection is a very effective preventive measure. The effectiveness of selection depends on the kind of transmission involved. If feeble-mindedness were determined in the same way as albinism, selection would be a very slow form of preventive treatment. More knowledge of the part played by the uterine environment in determining mental defect can help us to unravel the way in which gene differences associated with mental defect are transmitted. That heredity is the culprit in one framework of environment is fully consistent with the possibility of discovering a complete cure in another. Heredity has condemned the Mexican salamander to lifelong cretinism. In dealing with land situations it has what the educational psychologist might call a mental age of one month. A single meal of ox thyroid suffices to induce it to complete its full development into the typical land salamander in six weeks. In that condition it may live for years. There is little doubt that genetic factors play some part in the ætiology of cancer. People do not declaim with indignation against the expenditure of large sums upon cancer research, when such research is largely directed to display relevant environmental agencies such as coal-tar products.

Discussion concerning the advisability of a policy of sterilisation of feeble-minded individuals has suffered greatly from lack of a well-balanced perspective. No doubt a rationally planned society in which every individual contributed his or her share of socially useful work would treat the feeble-minded group within the community as a parasitic growth to be exterminated with whatever efficient means scientific

knowledge can prescribe. The sympathy with which such proposals are greeted at present by many students of social problems is not enhanced by the fact that they are usually put forward by persons who are anxious to perpetuate more disastrous and costly forms of social parasitism. The apathy, prejudice, and selfishness which permit highly gifted people to tolerate social arrangements which may wreck civilisation in our own lifetime and prevent them from making a scientific and impartial study of the immediate dangers with which we are beset are a greater cause for alarm than the prevalence of simple primary amentia.

The recklessness with which writers of the eugenist school have antagonised enlightened and humane sentiment by attacking educational expenditure, advocating a high infantile mortality of the poor, though not of the rich, as a device for improving the race and demanding reduction of social services in general, is all the more pitiable because some of their proposals are capable of being considered on their own merits without undue emphasis on the purely economic aspect of the problem of mental disease. As a biologist the writer thinks that more might be said for than against compulsory sterilisation for certain conditions. As a citizen he refuses to be horrified by the present expenditure on mental diseases, while civilisation is burning its wheat, cotton, and coffee crops because it has not devised a rational system for controlling production and distribution of the amenities which science creates in such profusion. The problem of mental disease is worthy of earnest consideration. When the worst has been said about it, it is not likely to become an insoluble problem during our own lifetime. The problem of world peace may assume disastrous dimensions within the next decade. Great Britain spends rather more than ten times as much on armaments as upon all classes of mental cases. At any moment Western civilisation may be plunged into a war which will destroy it irreparably. Those who hold this view will regard the type of insanity which leads eugenists to contemplate with equanimity present expenditure on armaments as a far greater menace to civilisation than the upkeep

of a few witless and voteless creatures in our poorhouses. Obviously it is not a matter of scientific judgment whether one chooses to deplore the fees paid to dukes as mining royalties or the fees paid to doctors for the care of the defective and insane. It is a matter of political taste.

MEDICINE

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MODERN medicine is so vast a system that it must have had a long history. Under the code of Hammurabi (*c.* 2000 B.C.) the doctors were an organised body of men with scales of fees for particular services to man and beast. This means that medicine, both as a science and as an art, was already old and had its traditions. In one form or another, as it emerges from its complicated matrix of primitive beliefs, medicine is consciously conceived and developed as one of the primary agencies for the conservation of life; for securing to the human person the greatest physical and mental fitness for all the duties incident to his development, and for directing the improvement of the environment throughout the whole earth. How medicine fought the weary fight that has ended in the relative freedom of today history tells us with much detail. With some definiteness we can indicate the big step from magic to science; from the controlled philosophies of mediævalism to the relatively "free philosophising" of the last hundred years; from science fearful of being heretical to science developed into its consequences without afterthought. This, indeed, is the problem of all modern science; but medicine had a leading, if not the chief, part in the fight, for in medicine correctness of fact is often a matter of life and death, and, in the end, the fear of death invites the healer and conquers intolerance. The whole world wishes for health and strength. The wish does, indeed, keep magic alive; but the doctor is no longer a heretic, and his services are not rejected because he is thought to be a materialist.

The attitude of the modern doctor to history is finely shown in Osler's *Evolution of Modern Medicine.* In a survey

such as this, the discoveries, generalizations, and theories of medicine are made to appeal to men, not as utterances of authority to be obeyed, but as conclusions rationally grounded in observation, experiment, and verification. The enemies of scientific freedom are still innumerable, and they are still active. But informed surveys such as Osler's are the best guardians of scientific freedom. They give a picture of social human growth from the medical standpoint.

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Let us study some of the great leaders. They will take us at a few strides into the heart of medicine as the modern world knows it. In Greek medicine there were many great names, but by the consent of history the Father of Medicine is Hippocrates. In his hands medicine changed from an occupation to a profession. He claimed for it a distinct and sanctified place in human polity. He or others acting in his spirit placed the profession on the highest level of ethical sanctions. The oath of Hippocrates is still a formula for the spirit of honourable medicine. Some of its obligations were that the doctor should regard the teacher of his art as equally dear to him as his parents; he was to share his substance with him and relieve his necessities, if required; to look upon his offspring on the same footing as his own brothers, and to teach them the art, without fee or stipulation. By precept, lecture, and every other mode of instruction, he was to impart a knowledge of his own art to his own sons, and those of his teachers, and to disciples bound by a stipulation and oath according to the law of medicine, but to none others. Here we note that the oath is by way of being a creed of a new service. The doctor is to follow the system of regimen which according to his ability and judgment he considers of benefit to his patients, and abstains from whatever is deleterious and mischievous. Whatever in connection with his professional practice, or not in connection with it, he sees or hears in the life of men which ought not to be spoken of abroad, he will not divulge, as reckoning that all such should be kept secret. Here sound treatment is linked with confidentiality. The essence of the doctor's relation to his patient today is defined

by these two points. The departure made by Hippocrates was thus a creative moment in European civilisation. But even more important for the advance of medicine was his method of study. He based all his work on direct observation of the cases; he built up case records, and on that basis rested his judgment of treatment or his forecast of cure. He recorded the successes as well as his non-successes, "believing it is valuable to learn of unsuccessful experiments and to know the causes of their non-success." He set aside charms, incantations, and astrology, as well as the irrelevancies of certain current philosophies. The essence of the problem was that to understand sickness the first study must be the sick person. He seems to have known the curative force of nature and recognised its powers to restore the normal state. The details of his "humours" and other points are of little consequence today; but the clearing away of irrelevancies and the settling down on direct study of the clinical facts are in the spirit of modern medicine. His method was the method of inductive science. Let it be recorded that Hippocrates (460-370 B.C.) was a figure in the great age of Athenian democracy.

The next very great name is that of Galen (A.D. 131-201). He was a man of amazing versatility and originality. He left no part of the medicine of his day untouched. Anatomy, physiology, pathology, materia medica, all benefited by his applications of system. He wandered over the civilised countries of the Mediterranean and brought to medicine something from them all. Animal dissection, functions of muscles, functions of nerves, experimental paralyses by section of the spinal cord, anastomoses of the capillaries, the demonstration that an excised heart will beat outside the body, contractions of excised muscle independent of volition or nerve-supply (tonus, or Sherrington's active posture), and many other points were studied by Galen, and some of his problems are still with us.

But instead of developing the methods of Galen's original researches, mankind more easily and more readily accepted his authority, and, in spite of his works being "a gigantic

encyclopædia of the knowledge of his time," his errors, as well as his discoveries, dominated medicine for about 1,400 years. "After his death European medicine remained at a dead level for nearly fourteen centuries" (Garrison).

Yet here was a man who showed how to question nature by experiment and how to record the answer. The "Galenical" preparations are largely to this hour the basis of our materia medica. Galen made a great stride forward in the study of the conditions of health, in the application of drugs, and in the consideration, both mental and physical, of the patient's personality. It was not his fault that, after him, medicine in Europe stood still.

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It is for general history to explain the failure of Europe to continue on the lines opened up by Galen. But medicine, if it soon forgot the value of direct study of nature and man, was not idle. The closing of the philosophical schools of Athens by Justinian in A.D. 529 was a symbol of some vast catastrophe in human thought, and medicine suffered with every other study. Greek ideas fled to Arabia. It is to Arabian scholarship that the later centuries were largely indebted for the restoration of classical science and literature. In medicine one great Arabian name stands out—Avicenna. "He is the author of the most famous medical textbook ever written. It is safe to say that the *Canon* was a medical bible for a longer period than any other work" (Osler). Avicenna had a genius for system, and made into one the ideas of Galen and Aristotle. The book became an infallible oracle and, according to Neuberger, "an edifice of fallacy." But Avicenna was "at the same time statesman, teacher, philosopher, and literary man." Arabia developed hospitals, which were "well organised and were deservedly famous. No such hospital exists today in Cairo as that which was built by Al-Mansur Gilafun in 1283. The description of it by Makrizi . . . reads like that of a twentieth-century institution with hospital units" (Osler). The creation of institutions is as important

as the discovery of principles, and we must allow for the larger rhythms of growing civilisations.

Avicenna's date was 980-1037. If the seven hundred years after Galen must be left blank, much thought was in process of elaboration, and Europe benefited by it when, in due time, the stream flowed back. If Averroës, a Spanish Moslem, was persecuted for being a pantheist, that showed that the Arabic mind was living and thinking and that one orthodoxy, like any other, takes fright at individual men.

But, if authority remained dominant, the genius of discovery was growing. Roger Bacon (1214-1294), scholar, physicist, inventor, physician, and monk, wrote: "Experimental science has three great prerogatives over other sciences; it verifies conclusions by direct experiment; it discovers truth which they never otherwise would reach; it investigates the course of nature and opens to us a knowledge of the past and of the future." This man, says Osler, "is mentally of our day and generation." But he stood alone. At the instance mainly of his fellow Franciscans, he was at least twice in prison, one of the periods extending over ten years. In the modern world this is not a recognised method of encouraging medical research. The fear of knowledge in those days must be classified as insane. Seven hundred years after his birth, Oxford, where he worked so long, has the honour of publishing many of his writings. This is as symbolic in its age as Justinian's decree of 529 A.D. The schools of free philosophy are open again.

It shocks the modern mind to find that Arnold of Villanova, "a strong advocate of diet and hygiene," a learned and prolific writer, "was an early heretic and constantly in trouble with the Church, though befriended by Popes on account of his medical knowledge"; that Peter of Abano, known as the Conciliator, the author of eight of the 182 medical books printed before 1481, was a reputed magician and, like Arnold, "appears to have been several times before the Inquisition. Indeed, it is said that he escaped the stake by a timely death" (Osler). As time marched forward these rebels grew more numerous and bolder. But from any standpoint the story is

a sad one. Perhaps, as Osler thinks, the concentration of the Western mind on the preparation for the life after death made men indifferent to the conditions of living in this world. He remarks with some acidity: "In this unfavourable medium for its growth science was simply disregarded, not in any hostile spirit, but as unnecessary."

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Paracelsus, Vesalius, Harvey—these three were the giants of the sixteenth and seventeenth centuries. Those centuries "did three things in medicine—shattered authority, laid the foundations of an accurate knowledge of the structure of the human body, and demonstrated how its functions should be studied intelligently" (Osler). Of Paracelsus (1493-1541) it is enough to say that, in spite of the fantastic life he led, the list of discoveries assigned to him in chemistry and general medicine is astonishing. He discredited Galen, whose medicines were largely from the plant world, and introduced the use of metals, such as mercury, calomel, iron, antimony, and others. His was the "first great revolt against the slavish authority of the school. . . . Paracelsus stirred the pool as had not been done for fifteen centuries" (Osler). "Alchemy is to make neither gold nor silver: its use is to make the supreme sciences and to direct them against disease" (Paracelsus).

Vesalius (1514-1564) was the father of modern anatomy. It is not here possible to show how much this meant at the beginnings of really scientific medicine. He was "the most commanding figure in European medicine after Galen and before Harvey. He alone made anatomy what it is today—a living, working science" (Garrison).

With Harvey (1578-1657) we are now well within the era of modern medicine. The story of his experiments and his discovery of the circulation is too well known to need more than a reference. The old theories of the heart as the centre for heat or the organ of intelligence had not disappeared in Harvey's day. His discovery and its reasoned proof may well

mark for us the real end of the unscientific period and the sure beginning of the scientific.

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Let us take one name from the nineteenth century—Claude Bernard. His work as a whole is typical of what is best in science. It was of this pupil that Magendie said: "You are a better man than I." He developed physiology as a positive science, ignoring mythologies of tradition and solving his problems by the direct method of analysis, hypothesis, and experiment. This was not all. He held strongly that the aim of physiology was to throw light on diseased conditions. On this ground he has been described as "the founder of experimental medicine." His broader generalisations have been a mental framework in the advances of modern physiology. And his many researches on the liver, the brain, the glands of "internal secretion" (his phrase), to name only these, have shown how complicated problems in living matter are to be solved. A great many specific inquiries are associated with his name. Garrison particularises his courses of lectures on experimental physiology (1855), the effect of poisonous substances and drugs (1857), the physiology and pathology of the nervous system (1858), the liquids of the organism (1859), experimental pathology (1872), anæsthetics and asphyxia (1875), and operative physiology (1879). These all indicate that he was a man of universal interests, a Hippocrates of the nineteenth century. He had imagination, invention, practical sense, superb skill in the technique of experiment, and the active scepticism that stamps the scientific mind. His general attainments were encyclopædic. He began life as a poet and dramatist, but, on advice, turned to medicine. It would be difficult to name anyone that combined in a greater degree the graces of literature with the clarities of science.

Here, therefore, we drop history and pass to the conditions of our own day.

The qualities of Hippocrates' mind are needed in every age. Beliefs, like diseases, may be epidemic. Sections of

mankind become infected by false beliefs, and constitute as great a danger as a physical scourge.

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In 1912 a research fund for a single purpose was created under the first National Health Insurance Act. This led to a Medical Research Committee. This, in due course, and under the statesmanship of the late Earl of Balfour, developed into the Medical Research Council as it is today. This Council is a department under the Privy Council. This means that, as the Privy Council is not in the strict sense an executive department, everything done under it applies to the whole State independently of any administrative department. This point is profoundly important constitutionally. Many departments in the State throw up problems for research, and some of them have equipment for dealing with those problems. But the Medical Research Council can keep touch with all other departments and organisations; it can co-operate with them; it can advise and arrange until it is not too much to say that the Council is the chief organising centre for research in this country. Here we have science at its best, organised in the service of the community and retrying accepted theories wherever a doubt is thrown upon them. The nature of its immense activities can be gauged from the scores of elaborate reports and surveys issued under its direction. It is the organising centre for hundreds of researches. It has its special committees covering the whole area of medical problems; it has succeeded in gathering to itself capable and original men, and its organisation is so adaptable that all serious research in the country receives encouragement and assistance. The Council is in touch with the laboratories of the medical and scientific schools, both in this country and abroad.

The formula adopted by His Majesty's Government to define the field of medical research, work to which an annual Parliamentary grant in aid is made, is as follows: "Medical research deals with the proper development and the right use of the human body in all conditions of activity and environment, as well as with its protection from disease and accident

and its repair." In a discourse at the Royal Institution on "The Scope and Needs of Medical Research," the late Sir Walter M. Fletcher analysed this comprehensive formula. It covers inheritance and nutrition, genetics, energy values of diet, sleep, relation of climate to bodily activity, innumerable problems of industrial life, the optimum of work, the optimum pauses, hours of work heavy or light, shift systems, the effects of monotony in repetitive work, vocational guidance and selection, study of movements, posture, physique, prevention and palliation of disease, faults of environment, parasitic enemies, vitamins, the welter of diseases like typhoid, sleeping sickness, malaria, and a multitude of others. The formula, it is clear, covers practically the whole of the uses of the body and the dangers it is exposed to; social as well as individual physiology; the physics, chemistry, and pathology of the environment of all the different climates; and, in a word, all that affects for better or worse the efficiency of the human organism in all its relations.

Our formula covers only the British programme, but it is wide enough to cover the researches of all other countries, and among the most useful reports are the summaries of work done all over the world in fields of which this formula may be taken as the major premise. It must not be supposed that the Medical Research Council is an exclusive organisation. On the contrary, it aims at stimulating the innumerable researches of the schools of medicine and science in this country and also at collaboration with the schools abroad.

The researches conducted in the schools of tropical medicine show how the great tropical diseases—malaria, yellow fever, cholera, and plague—are handled. It is common knowledge that, by the extirpation of yellow fever and malaria, the area of the Panama Canal was, as one American doctor has said, converted from a nest of diseases into a health resort.

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In these twenty years or so the discoveries of Sir Frederick Gowland Hopkins and fellow-workers of other countries on food alone, have transformed the whole theory of diet and established a new scientific groundwork for the investigation

of nutrition. The discovery of the accessory food factors, or vitamins, ranks among the great discoveries of history. After ten years the Council has issued a second edition of its survey of present knowledge in this field. The survey includes thousands of references to work done. It is hardly necessary even to name the vitamins whose properties are here detailed, but they cover problems of growth, reproduction, defence against infection, specific diseases like rickets, beri-beri (a nervous affection), scurvy, dermatitis, pellagra, and many other nutritional conditions. The number of vitamins now known or suspected is about ten. Their partial isolation involves the most refined methods of physical and biological chemistry. The diseases named are regarded, some with certainty, others provisionally, as "deficiency diseases." The masses of facts determined by experiment are available for application to the human organism. It is only a matter of time and administration for diseases like rickets, beri-beri, scurvy, and many related affections of nutrition to disappear from the human race. Of vitamin D, known as Calciferol, the anti-rachitic vitamin, Sir Walter Fletcher says: "In pure form this has an almost incredible biological potency. A single ounce of it would suffice to give a full daily ration for a million growing children." This substance has been isolated in pure crystalline form. The others are used in the form of concentrates. The chief practical result for medicine is that all those substances can now be standardised, and the administrator will in time have to persuade the community to secure that supplies of every such essential substance shall be available for every expectant mother and every child born.

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Within the last half-century or so drug therapy has been greatly simplified. The drag-net prescriptions of previous days have largely disappeared. The refinements of pharmaceutical science have ended in the greatest precision of dosage. The resources of modern chemistry have been applied to the forming of new drugs of endless variety. These are all tested biologically and clinically before they go on

the market. They are known to have definite effects on definite organisms; the guesswork sinks to a minimum. The science of pharmacology keeps whole sections of the medical and pharmaceutical professions in constant activity. The minuteness of experiment and careful verification exceed anything known to the past. The British Pharmacopœia of 1932 is not simply a new edition of an old document. It arose out of the work of a special Pharmacopœia Commission, who heard experts in physiology, in pharmacology, in pharmacy, and in therapeutics. It is a handbook of tested materials and includes whole departments unknown to previous editions.

There are several therapeutic substances that must be tested biologically. These include anti-rachitic vitamins (vitamin D), anti-dysentery serum, diphtheria anti-toxin, gas-gangrene anti-toxin, tetanus anti-toxin, insulin, old tuberculin, pituitary (posterior lobe) extract, and a series of special drugs such as digitalis, strophanthus, and certain arsenical drugs used in the treatment of syphilis. For all these the tests are standardised by international agreement. The manufacturers are subject to the most minute regulations. In Great Britain their products must be submitted to the National Institute of Research and passed by it before being put on the market. These extraordinarily severe restrictions are due to the extreme delicacy of the drugs, their liability to go wrong, their great potency, and their immense value in the treatment of disease. The international control was arranged through the Health Section of the League of Nations. The result is that the communities can rely on obtaining correct material correctly tested. This is a medical departure of the first magnitude. Other substances of the same class will, in time, find their place under the regulations. Meanwhile, the world is protected so far as correct scientific technique can protect it.

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History shows that food has played a part in therapeutics for centuries. But in the last generation two special dis-

coveries have compelled a revisal of all food values: these are the discovery of vitamins and, in particular, the discovery of insulin. Perhaps in this regard the acid-base equilibrium of the blood should be reckoned as a fundamental guide to correct diet. Correct diet is the diet that maintains nutrition without producing any deficiency disease. Perhaps, too, we may add the discovery that liver is of special value in some anæmias.

Insulin is the secretion of special gland cells within the pancreas. Its absence involves diabetes mellitus; its presence prevents diabetes mellitus. Hitherto the treatment of diabetes has had to rest mainly on modifications of diet, in particular the amount of carbo-hydrate consumed. Now that insulin is available in treatment, the carbo-hydrate diet and the amount of insulin are adjusted to each other until, by the combination, the amount of sugar in the blood is maintained at a correct percentage. Roughly, it may almost be said that no one need now die of diabetes.

But correct diet for other morbid conditions has benefited with the experience in diabetes. The diet must produce enough heat and it must have its complement of vitamins. The restudy of foods from this point of view has ended in many radical modifications. It may now be said that, apart from the special diet for particular diseases, the maintenance of the body in health demands specially constructed diets correctly cooked. This is a very large field, but it is of growing importance in the treatment of disease and the maintenance of health.

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Modern methods of diagnosis have been greatly developed in the last generation. They include improved mechanisms such as the polygraph and electro-cardiograph to indicate the cycle of the heart; the classification and staining of the blood cells as they alter in particular diseases like pneumonia; tuberculin testing of the organism for active tuberculosis; chemical testing of the blood for disturbances of the acid-base equilibrium; the Widal test for typhoid fever; susceptibility

tests for diphtheria and scarlet fever; X-ray examinations for conditions of internal organs; and many other tests, some older, some more recent. All these tests have been based on prolonged experiment and experience. But every day brings forth more ways of making diagnosis easier and surer.

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New methods of treatment keep pouring out of the laboratories and the clinics. The large textbooks and encyclopædias are now supplemented by books showing the "advances" in diagnosis and treatment. Every six months may produce a body of new researches on twenty different lines. The documentations of these volumes are incredibly extensive. It is, therefore, useless to offer any further detail in this sketch. The general principles long established are, of course, honoured—rest in pain, cooling of the body, clean air, light. It is common to see acute illnesses like measles, whooping cough, pneumonia, pulmonary tuberculosis, and others treated in the open air and sunlight. This is a revolution compared with even a few years ago. There are also the specific treatments for infectious diseases. Strange discoveries never cease; for instance, a benign form of malaria is now largely used for the treatment of general paralysis of the insane, which is due to syphilis. Many infections are still a mystery; their viruses—we must not say micro-organisms—are too small to be seen with the ordinary microscope or to be strained out by the finest known filter; they are "filter-passers." But the laboratories and the clinics are busy with them. Treatment by special drugs has reached a stage of great simplification and refinement. A modern marvel is the treatment of syphilis by arsenical preparations. Some twenty years ago this disease was practically "incurable." Today it is curable, given the time and the patience dictated by its peculiar natural history. And that principle applies to all the infections: the treatments are adjusted to the natural history of the germ. Even with the great diseases—cholera, plague, malaria, and leprosy—the methods of treatment are improving from year to year, and the conquest of them all is a

matter of time. In any well-equipped hospital the treatment of drugs is a well-organised system, but this is supplemented by facilities for massage, remedial gymnastics, X-ray applications, deep therapy apparatus for cancer, radium, diathermy, electric baths, ionisation, foam baths, hot and cold applications of many varieties, light, ultra-violet rays. The rest methods in treating tuberculosis are full of ingenuities. Needless to say, the inventions applied in surgery are without end. Outside the schools, there are all the tested practices of the health resorts.

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The doctor and the nurse have for ages been a working team. But modern medicine includes, also, health visitors, almoners, special social investigators, skilled lay assistants of many varieties, as in eye diseases, ear diseases, surgical appliances, rest jackets, plaster-work, and the like. Of these lay services, one of the most important is the social investigator. In 1909, Richard C. Cabot, M.D., published a small book on *Social Service and the Art of Healing*. He found that, particularly in the out-patient departments, the prescription of medicines, say, for some form of dyspepsia was largely useless because many patients were living in social conditions that aggravated or caused the trouble. Out of these considerations arose the whole system of social services now attached to the large hospitals. Social workers of the right disposition and trained in the right way make inquiry regarding the cases allotted to them where it is supposed that a nervous factor, or a worry factor, or social difficulties of some sort, may be involved. Confidential reports are made. The patient is put in touch with the appropriate relief services. The dyspepsia or the neurasthenia disappears rapidly because the social causes of the disease are removed. This means that the doctor is treating, not an abstract disease, but a sick person in the concrete conditions of life. The system is spreading in every community.

Public health includes the hygiene of the environment and the management of infectious diseases. In the modern developments it covers also the provision for maternity and child welfare services. In the broad sense it must cover also the provision for old age, feeble-minded, lunacy, and the diseases incident to poverty. All these are within the control of the public health authorities. To this may be added school health administration, which involves the examination of millions of school children. There are still other items, but space forbids further enumeration. All these activities are preventive; but there is a special use for prevention in the treatment of individual persons suffering from general diseases. This form of prevention has, as yet, gained little momentum in medical education or in treatment. But a type of what we mean is the assessment of fitness necessary for civil or military occupations; for here the problem is not what disease does a man suffer from, but whether he suffers from any disease, and if he is healthy, what work is he equal to. In many of the great services of civil life the assessment of fitness is the primary purpose of medical examination. But in the ordinary work of medicine the doctor is called in only when the patient is sick. For the assessment of psycho-physical fitness, however, the patient's condition must be examined by skilled persons, whether illness is present or not. The insurance companies are all guarded by minute medical examination. But this class of preventive work has not yet found its way in any great degree into the teaching schools. This, however, is a class of work that is developing rapidly outside and will ultimately become the predominant work of the medical profession. For the moment this type of prevention is generating special clinics, such as heart clinics, of which, in 1925, there were forty-seven (with some 12,000 clients) in New York City alone. It is also generating associations for making periodic medical examinations of members, independently of their being ill. This periodic "vetting" is said to improve the life expectation of the individual.

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At no time in the history of this country has so much attention been given to the study of psychology. Before the War the study of insanity had behind it a long history. But the War gave an immense impulse to the study, not of insanity only, but of psycho-neurosis in every variety and degree. Even before the War feeble-mindedness had already established a claim on the public authorities, but since the War this study also has gone rapidly forward. For the acute insanities provision has been made for several generations in large asylums. The term "asylum" is now dropped, and those institutions are mental hospitals. This is not a mere verbal difference, for the study of insanity has itself changed. The insanities are of many varieties; some of them are due to toxins, others to degenerations, others to mere functional exaggeration of physiological conditions, and others are incidental to certain diseases. But through the whole field the insanities are studied as a compound study; that is, they involve both the mind and the body. No matter what view is taken of the relation of mind and body, whether the body is assumed to be possessed by a special substance called mind or whether the mind-body is to be regarded as a single substance with two aspects, or whether we look at it more broadly as two series of events running parallel with each other—in all cases the mind-body has to be regarded as a unity. To attempt to treat the body without considering the mind or to treat the mind without considering the body is equally futile. The human personality must be treated from both standpoints at once. When the patient becomes insane the nutrition of the whole body is affected. Reversely, when the body is affected by certain toxins the nervous system may undergo degeneration and the mental symptoms may be a form of insanity. For instance, in pneumonia it is common to have delirium. Similarly with typhus fever and many other fevers. When the toxin is eliminated the mental symptoms go. It is now the custom for the expert in insanity to test the organism for possible poisons; for instance, the toxins of specific fevers. In these cases the mental symptoms are really a delirium due to poison. On the other hand, a primary insanity may be due to

degeneration of the brain. The symptoms and treatment are wholly different. But in all cases the body or mind or the mind-body must be regarded as a unity.

Hitherto, in this sketch, we have dealt only with the physical side. But in the modern curriculum provision is made for the special study of normal psychology, morbid psychology in all its phases, and the psychology of acute insanity. But modern treatment tends more and more to search out the very early cases, where, perhaps, only some slight functional signs indicate instability. These are treated by relevant physical methods—baths, massage, and other applications—and, treated thus early, mind and body may be restored to normal. The professor of psychiatry covers the whole range from passing obsessions up to the major insanities. But, above all, he is in a position to show how fundamentally important it is never to forget either side of the human organism. As Bain said in his *Mind and Body* over fifty years ago: "The mind is destined to be a double study—to conjoin the mental philosopher with the physical philosopher; and the momentary glimpse of Aristotle is at last converted into a clear and steady vision." An old and learned medical friend, who had shown heroic fortitude through years of suffering, once said to me in a voice of passion: "What I need is a man that can grasp my whole personality." That is the right standpoint for the educated physician. Physical health and mental health are aspects of the same problem, and the man that neglects either will fail in both.

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It is common and easy to say that "progress" is an illlusion of the nineteenth century. But in every section of medicine progress has a definite meaning and, as a rule, can be tested. For instance, if the average duration of life has become greater in a given period, it is right to ask whether medicine has had a part in this extension. Fortunately, by the elaborations of the systems of insurance this problem can be dealt with quantitatively. The birth-rates and death-rates are now

available in every civilised society. The numbers living at given ages are carefully compiled from the census. The numbers living and the numbers dying can be so arranged as to show whether one period is more favourable to long living than another. Briefly, the life-table can tell us the average expectation of life or the mean duration of life. And this life-table is scientifically constructed out of the actual societies of living and dying people. It is not an abstraction; it is a measure of a concrete phenomenon. If the average expectation of life is proved to be greater in one generation than in another, and if the increased duration is shown to be due to the better control of given diseases, medicine may claim a share in the effect. And the concept of the life-table has been applied scientifically on so great a scale that the life-table is a reliable measure of progress. The insurance companies construct their benefits on the basis of life-tables. It may be said, generally, that in the last few decades the expectation of life in civilised countries has increased materially.

The following illustrations of increased expectations are taken from *Health and Wealth*, by Louis I. Dublin, Ph.D.:

In England and Wales in period 1828-1854 the expectation of life at birth was 40·88; in period 1920-1922 it was 56·95. In Scotland, 1861-1870, it was 42·09; at 1921 it was 54·71. In France, 1817-1831, it was 39·55; 1908-1913 it was 50·46. In Italy, 1876-1887, it was 35·25; in 1910-1912 it was 47·38. In Sweden, 1816-1840, it was 41·53; in 1911-1920 it was 56·99. In Denmark, 1835-1844, it was 43·65; at 1921-1925, 61·10. In the United States, 1901, it was 49·24; in 1926, 57·74.

Thus in England and Wales there has "been a gain of sixteen years in the interval of eight decades." In a similar period Denmark shows a gain of seventeen and a half years. Massachusetts showed a gain of fifteen years in sixty-five calendar years.

Tuberculosis is declining rapidly, but some of the diseases of middle and advanced age are not. The special analyses of a great insurance company's claims tell us definitely which diseases are most deadly. Dr. Dublin is thus able to make

reasonable forecasts of the probable extension of life in the coming generations.

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The medical curriculum has two primary purposes: first, to maintain the scientific groundwork of medicine by providing recruits for teaching and for research; second, to maintain the numbers of trained doctors necessary to provide medical diagnosis and treatment for the community.

The curriculum, therefore, must include discipline in the fundamental sciences of physics, chemistry, biology, anatomy, and physiology. It must equip the student with a knowledge of diseases by courses in pathology and bacteriology. It must teach him how to apply his knowledge in practice by courses in pharmacology, therapeutics, systematic medicine, clinical medicine, systematic surgery, clinical surgery, midwifery and diseases of women, public health, medical jurisprudence, and in many other subsidiary applications of the sciences to practical diagnosis and treatment. At one of the chief medical schools the courses, long and short, number forty-three. These are spread over five years. In some schools, to prevent over-pressure in any single term, the course has been extended to six years.

These courses are the ordinary obligatory curriculum for all graduates. The schools also provide special courses for diplomas and certificates. The curriculum must be such as to furnish the proper instruction for all grades of medical practitioner. These grades include private practice, National Health Insurance practice, public health service, school health service, Army, Navy, and Air Force services, as well as specialists of many other orders.

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Once registered on the Medical Register, the graduate becomes a qualified medical practitioner and passes under the statutory control of the General Medical Council. The Council may remove him from the register for certain classes of crime and also for conduct that, on inquiry, it finds to be

infamous conduct in a professional respect. He is free to practise any theory of medicine he chooses, no matter how far he diverges from accepted ideas. The holding or practising of any special theory of medicine is not, by itself, a ground for removal from the register.

In Britain the Medical Register began in 1858. From that time to January 1, 1932, 108,629 names were entered on the register. At the beginning of 1932 there were remaining on the register 55,604 names. The Medical Register for Great Britain and Ireland (including the colonial and foreign lists) contains a list corrected up to the beginning of each year of all those entitled to practise in terms of British registration.

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Yesterday, medicine was concerned with a searching for origins and a fumbling approach to a method. Today medicine is a vast system of ideas, discoveries, generalisations, theories, and practical proposals, all under discussion by thousands of experts. Tomorrow, it will be a problem of how to relate the imperatives generated in the course of history to the working values of life in the growing society of the future. How shall we formulate some of these imperatives? In our condensed sketch we have indicated the channels that have been formed for the energies of medical men in the conduct of their duty. But, after all, the world does not exist merely to get its sick persons cured. There must be some larger purpose. Medicine comes very close to the key-points of life. The healing of the sick has always and everywhere been accepted as among the highest aims of personal endeavour. In the modern world the private doctor is "called in" when a member of the family is ill. It is assumed that he is intellectually and morally qualified to have access to the intimate life of family or person. This is a fact of tremendous importance. It means that in the course of social evolution it has been found that the parents of children or the children themselves are open to innumerable afflictions that they do not understand and cannot meet. The doctor is the special servant created by the social needs to tackle and handle to a

good issue wherever possible, but in any case to handle, the afflictions that trouble the families. He is, therefore, an officer specially trained to cure where disease is present, to advise where conditions less than disease are present, so to guide the family that the father and mother are enabled, with him, to fight disease, that suffering may be relieved and death postponed.

In the presentation of medicine given above the "sanctions of medicine" were left to the last. They are the name for the organisation set up by Parliament to keep before every member of the medical profession the lines of honourable social conduct. Every year brings its quota of culprits. The offences vary from something relatively trifling to offences of the grossest order. And the investigation of these offences is not confined to an individual medical man acting as the accepted doctor of a family, but to the same man acting in his public capacity as a notifier of diseases, as a writer of certificates, as a person legally responsible for declaring the causes of death, as an insurance practitioner responsible for authorising the outlay of money on sickness, and he has many other official duties flowing from the fact of his being a qualified medical practitioner. Then, if we look to the public service, the medical officer of health has entry into every home when the public health is endangered by the occurrence of infection, or when the conditions of housing, or general environment, or occupation are injurious to health. Whole Acts of Parliament are loaded with the details placed under his executive.

Out of these special relations of the doctor to the community certain imperatives of medicine have arisen. Today our civilisation speaks to the doctor somewhat in these terms: "You shall not kill. You shall answer the call of sickness. You shall regard the sick man as already within the shadow of death and so in a place apart and to be treated with understanding and sympathy. You shall devote to him with your whole heart the knowledge and skill you have acquired. No matter whether he has been guilty of crime or anti-social conduct of any kind, you shall deal with him only as a sick

man to be saved from disablement or death. You shall not forget that, in the privileged position accorded to you and subject to the requirements of public justice, you are under obligation to maintain social confidence as between man and man. You shall fulfil the conditions of honourable service as these are set forth in the laws devised for your profession."

In the execution of these imperatives a man finds himself under strong ethical tension. To him no medical duty can ever be indifferent. He finds, each in his own measure, that the practice of medicine is the practice of life. Every hour is "a bringer of new things." From a trifle that may be ended with a word he may pass to a tragic emergency. He may have to face serious danger or even death in his dealings with the unconquered diseases at home or abroad. He leads a life that is never free from anxiety. To the varieties of pathetic experience there is no limit, and the doctor, if he preserves character at all, attains to a ripeness of sympathy and a social insight that give him an exceptional place in the service of man.

This is enough to suggest how closely the medical man lives to the values of life. He is in a very literal sense the friend of man. From the student thinking only of cases, he grows into the ethical philosopher, thinking only of persons. To this end medical experience is highly favourable; for, on the one side, the doctor is trained in the science of medicine, and, on the other, he is always faced with problems of human conduct. Medicine, both as a science and as an art, is thus peculiarly rich in the higher motives to action; for science is itself a primary value and the concrete life of the family is the genetic point of society.

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Ever since Darwin propounded his theory of the origin of species by natural selection there have not been wanting critics to say that preservation of the unfit necessarily involves the deterioration of the race. The logical inference of this hard doctrine is that the gross conditions of nature, conditions that are largely artificial in modern life, should be allowed to

work their full effect, and this is assumed to be the killing off of weaklings. From this standpoint medicine is one of the worst sinners; for undoubtedly the extirpation of diseases and the prevention of disease in individuals do have the result that more people with certain defects are kept alive longer than if our hideously constructed towns, our dirty ill-ventilated houses, our imperfectly constructed factories, and the multitude of other unhygienic conditions, were left to their natural course. Yet the criticism is rather superficial. It assumes that the indiscriminating attack of those lethal conditions is to be regarded as "natural" selection, when in reality they are the products of human ignorance and carelessness.

Let us look at the facts from the other end. The question we have to ask ourselves is something like this: "Is it a good thing that everybody should be as healthy as his inherited endowment permits him to be; as physically strong, as mentally alert, as ethically competent to face the day's duty? Shall we have a better society if reasonable care is taken to see that the child is born into worthy conditions; that he is well nourished in his first three years, the period of his most rapid growth; that, in his transit from infancy to adolescence, he shall have access to air, light, and exercise, that he may attain smoothly and naturally to his best physiological normal, and that, when he comes to take his place in the adult community, he shall do so with good teeth, good eyes, good ears, good muscular development, good heart and lungs, and good organs generally?"

To achieve this end means that the whole forces of the community have to be concentrated on the removal of evil conditions, on the control of disease, on the maintenance of health, on the educational discipline of individuals of all ages, on definite programmes of work adjusted to the special conditions of each community. To assume that the products of human inefficiency are conditions of nature is not legitimate reasoning. The environment itself is in a state of constant evolution and involves infinitely subtle readjustments of the organism. When the conditions of a growing society

are as perfect as man's energy can make them, it will be time enough to raise the question of letting the weaklings die.

What, then, is the real question? It is surely this: that, by the control now partially established over infectious disease, early deaths have fallen and lives are longer. The same result follows from the better treatment of all disease. The effect of these medical activities is an extended expectation of life. The result is that, as the working capacity lessens in advanced life, the burden on the community increases. This is not a reason for throwing persons of impaired vitality on the scrap-heap. Rather it is a reason for discovering fresh readjustments of labour to fit the impaired energies and economic readjustments to enable the community to keep the older persons in productive activity. In this problem we are only at the very beginning. The old age pension at seventy is one method tested in this country; another is the pension based on contributory insurance; and a third is the lessening of the burden of medical service by the increasing transfer of individual medical treatment to the larger communal units or even to the State itself. In all this there is a perpetual re-adjustment from day to day and year to year of the organism to its environment and of the environment to the organism—these two being always and everywhere supplementary to each other. If by preventing rheumatism we reduce early heart disease, we are, at a stroke, able to keep a greater proportion of young people fit for the work of industry. If by early care of mild heart affections we enable the man of middle age to add many years of work to his record, we are really maintaining the efficiency of the community as a whole. When, on the long run, heart disease asserts itself in the older ages, we are then faced with the economic problems of subsistence. When technical "old age" supervenes, civilisation says we shall provide for it.

Here medicine leads us into the heart of problems that affect the whole evolution of society. So far as fitness can be maintained, medicine is under an ethical obligation to maintain it. The problems following on this are problems for statesmanship, and, as only a few experiments have yet been

tried, it is too early to say that medicine is indirectly producing any deterioration of society.

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Eugenics is not an affair of medicine exclusively; yet it has medical relations. For the many specific affections that end in hereditary disabilities have to be investigated medically. All we need say here is that, by many institutions and much individual treatment, the effects of inheritable feeble-mindedness, to take only one instance, are largely prevented. The methods of segregation are spreading. It is not necessary here to restate the modern doctrines of inheritance. It is enough to say that in their latest interpretation those doctrines are shown to be not inconsistent with the work of preventive medicine.

The control of life in specific ways leads naturally to the larger issue: How far can medicine assist us in the control of life generally? Even from the details of our brief sketch it is obvious that the superintendence of growth is getting closer and closer to the real problem of social evolution. Through a hundred channels the science and art of medicine may become an effective guide in the control of life. Here we pass beyond the gross work of preventing infection, mending the disabled, and helping the diseases of the individual. The problem before us is no longer a problem of disease. We may assume that, sooner or later, much disease will disappear from the community; but even when all preventable disease is prevented, both in the community and in the life of the individual, the fundamental problem emerges—namely, the problem of continued good nutrition. Men, women, and children must be fed. The modern revelations of medicine are teaching us more and more in detail how to feed them correctly. This is a problem that can never be finally solved so long as the human race produces new children. But the solution will involve the energies of all the doctors, of the hygienic laymen, and of the services organised for the maintenance of health, physical and mental. At the moment this

is a far-off ideal, but the advances of the last fifty years are full of hope for the future.

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There are the many problems as yet unsolved; for example, cancer and its congeners. All we need say is that the surgeons work wonders by the excision of early cancer, and the research departments everywhere are getting closer and closer to the problem. Any hour may reveal the secret. Meanwhile the doctor must do his best, in this as in other incurable conditions, to reduce suffering, to make the bed of death as easy as possible for the hopeless mind, and to keep touch with the best that is known and done.

In the growth of society medicine is playing a very great part, and the future will find it playing a part still greater. The set purpose of medicine, to create a healthy community and so establish general happiness on a relatively stable foundation, seems here to coincide with the end of social ethics. If what I have said of the rich motives of the medical profession be true, even in part, the doctor is exceptionally qualified to maintain a sane outlook on social evolution and the statesmanship needed to direct it. Even in the ultimate problem of ethics—namely, the reconciliation of self-interest and the interest of the community—the medical man is well trained. His sympathies are likely to be fully developed, and every day he has to postpone his personal pleasure to his public duty. As Bain, in arguing the general case, says: "We are under a divided dominion; the best of us are always faithful to Society; the worst cannot entirely throw off allegiance. 'Am I not a man and *a brother*?' is the full expression of *Homo sum*." This is the main postulate of social ethics and offers a major premise for the art of medicine.

ANTHROPOLOGY AND MORAL EVOLUTION

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THE anthropologist premises that mankind should be taught to take a broad and impartial view of itself. History has always professed to prepare the ground for such a survey, but has remained essentially a history of civilization, and almost exclusively of Western civilization. Reasons good as well as bad could be urged for this attitude. The worst possible reason would be that we are the human beings whose private affairs matter most. The best reason, perhaps, would be that authentic history must rest on written records. But, to treat the latter argument alone seriously, the archæologist is certainly not going to allow that what he reveals by means of the spade is devoid of historical meaning. He might even hint that one was likely to unearth fewer lies in this way than by digging them out of books. Again, whereas history is clearly obliged to carry the past down to the present, the historian of civilization notoriously fails to do this effectively, because if he stands too near to matters of wide bearing and interest—as, for instance, the recent Great War—he straightway gets the facts out of focus. But the ethnographer, the student of primitive folk, whose history is more or less all in the present, claims that he is better qualified to see his facts in fair perspective; since in the first place they are themselves on a smaller scale, and in the next place the difference in culture between observer and observed produces on the mind's eye an effect of concentration not unlike that caused by distance in time. Ancient prehistory and modern prehistory, as the French term them, must have their weight, whether it be worth much or little, together with the history of the peoples who possess a literary past. The anthropologist

aims at a more universal outlook than the student in any other branch of the humanities.

Something more, however, must be added before his real position is disclosed. In order to satisfy the anthropologist, this universal history of mankind must be construed as a natural history. A natural history of religion must by abstraction disregard altogether the possibility that the religion may be revealed. Natural here means biological, and biological in its turn means evolutionary. Anthropology is among the biological sciences and accepts their naturalistic and evolutionary outlook. Hence in setting out to compose a universal history of man it takes over from general biology two main postulates. The first of these is that there is strict natal continuity between all the forms of life, and consequently that the appearance of our species on this earth was due to no special creation, but to what the geneticist knows as mutations. The second is that Man belongs to the class of organisms that is integrating or evolving; in other words, that from its first appearance onwards in time the human race has experienced no Fall of Man, but on the whole has been growing more highly organized, primarily as regards its bodily and mental constitution, and secondarily in respect to the culture—the set of habits—resulting from this change in the hereditary nature. On both these points our fathers, taking the Genesis story at its face value, believed differently. Now, although science is bound to no creed, modern anthropology holds so firmly to these two working assumptions that here it would not be worth while to discuss their validity; for, if they go, anthropology goes too, and we must begin all over again.

If, then, so late as the year 1600 Giordano Bruno went to the stake for writing, "With Pythagoras I regard the Earth as a star," the anthropologist may yet have to suffer persecution for saying, "With Aristotle I regard Man as an animal." Nevertheless, the doctrine that Mankind is not part of the order of Nature is surely too unreasonable to prevail. We palpably have bodies besides souls, though the philosopher is mystified by the soul's need of a body; for he prefers to put the problem of their interconnection in this order rather than,

with the naturalist, the other way round. Astronomy has ceased to be geocentric, but philosophy remains anthropocentric. It insists that mind is the measure of all things, and reminds the natural sciences that they are expressions of mind, and hence that their Nature is a sort of mental projection. This is a point of view which the sciences have only very recently shown any inclination to accept. As long as the Newtonian physics was unchallenged, matter appeared capable of walking through mind, as Tiresias was fabled to do when allowed to retain his bodily substance among the ghosts in Hades. The physical categories can now boast no such coarse advantage over the spiritual. For a cosmo-physicist a radically indeterminate universe is a possibility to be seriously contemplated. To the old-fashioned scientist such a thought was shocking. It is shocking, too, to some philosophers. There are philosophical absolutists who have difficulty in rebutting the charge that they are determinists. Both schools of thought —the Newtonian physicists and the Hegelian metaphysicians —presume a commensurable order of things. If Nature in its objective and subjective aspects is not completely susceptible to the application of mathematics, both sets of thinkers are at fault. Philosophy, unlike physics, can still invoke the voluntarist theory of the universe. Freedom is no absurdity, because we know it in ourselves. Yet a *Deus sive Natura* who is essentially a Free Will is not satisfying to the logical mind, because such a theory threatens to dethrone reason.

It may be that a new cosmology, such as is destined to bring the scientist and the philosopher more closely into agreement than ever before, is in process of formulation. That theology would gladly acquiese in such a scheme of thought which identifies the central principle of mind with a creative activity inspired by love is probable. For theology has never been rationalist in temper even when it has done its best to appear so. It can never be much more than an echo of practical religion, which has throughout its entire history been largely content to act first and justify its action afterwards. Its explicit creeds have had little more than a political significance; whereas its inarticulate faith has kept it true to

a moral direction which is approximately uniform, according to the testimony of the universal history of Man.

At this point it becomes clearer how anthropology may help mankind to a truer and better world-idea, or world-intuition. If the history of mankind shows that it has been orthoscopic, or rightly aiming, in the pursuit of good, then there is some point in life. But does history show anything of the kind? Can any history give unprejudiced evidence? This is perhaps where it is of advantage for an enquiry to be associated with the natural sciences, which have had little temptation to distort their facts as compared, say, with political or religious history. For the anthropologist, who is just one kind of historian among the rest, calls himself a man of science, and by so doing undertakes to write the most unbiassed and objective history that human nature can produce. Thus, firstly, as regards uncivilized man, on whose affairs his authority is not disputed, whereas his references to civilization are resented, he is careful to represent the savage neither as a beast nor as a god, as did philosophers in the pre-anthropological age when disputing whether the state of Nature was one of war or of peace. Secondly, he tries to avoid any *à priori* identification of organic evolution with betterment. For him the word implies no more than the process of becoming more complex; and it is no part of his evolutionary presupposition that man has done well to abandon the simple life. This is a question of value, not of fact.

Yet if it be asked whether the course of human life has been an emergence or ascent due to an immanent will to live well, it is obvious that the wide survey of the historical evidence which anthropology offers is bound to be exceedingly helpful. Anthropology is a science, not a philosophy, of Man. Indeed, anthropologists of the present day are in close agreement concerning the limits of their special task. Working on the very mixed material provided by somatology, technology, linguistics, and the study of institutions, they try to make these studies converge on ethnological problems—namely, questions concerning the historical formation, dis-

tribution, and survival of ethnic groups or peoples. It will be noted that they are prepared to explain how, if not precisely why, some types of human society survive while others perish.

Hereupon a philosophy of human history is needed such as will submit the bare facts of the time-process to analysis in the hope of discovering some normal relation between merit and destiny. The exceptional cases must be explained or, better, shown to afford indirect proof of the rule. The thinker who undertakes to justify the workings of the Good Will immanent in humanity by reference to the entire human record must be ready to become absorbed in the concrete. The ideological philosopher who speculates with definitions of the *Summum Bonum* will not be of use. But if one whose mind has received a thorough training in philosophy, and acquired the synthetic grasp which such an education can alone confer, will take the trouble to acquaint himself with the detailed findings of the anthropologists, he may be able to prove whether the biological evolution of man has also been accompanied by a moral evolution.

An instance of the kind of work wanted is to be found in that admirable treatise *Morals in Evolution*, by the late Professor L. T. Hobhouse, which reveals a patient and critical scrutiny of the anthropological data, and yet exceeds anthropology in its attempt to establish a general law of human progress. As compared with the best work of the pure anthropologist such a philosophical interpretation of human history may, perhaps, never attain the same pitch of objectivity. Philosophy is to science as poetry to prose, putting a severer strain on the constructive imagination and consequently embodying more of the personality of the author. It is thus by no means certain that another who endeavoured to deal with the same facts in the same synoptic way would reach the some results.

If one interprets Man's career through the ages as on the whole making for good, it is largely because of his own faith. He, too, is man, with no reason to suppose himself untypical. An affirmation supported by introspection must be the *funda-*

mentum rei. We go to history in order to confirm our hopes, and even if it tells us that the world is against us we may decide to hope and act in defiance of the world's experience, which is not final and can be altered. Yet on the whole history is a sound critic of human endeavour. By its aid we can test our most cherished beliefs; and, if they seem in the light of the past to be false, it would be prudent to modify them accordingly.

In the rest of this paper one whose studies have been divided equally between anthropology and philosophy will attempt a brief estimate of the moral value of the evolution exhibited by primitive society. He trusts as an anthropologist that his facts are correct, but would have it noted that he is deliberately overstepping the borders of the anthropological field when he ventures to moralize on the meaning of the facts of history.

Man has often been termed the rational animal. Of what avail would that be if he were not also the moral animal? Here, then, the question for us will be, How far is the savage a moral being, and one who is gradually advancing in his type of morality? The higher the type, let us assume, the more self-conscious—in a word, the more ethical—it will have become. Away with the pessimistic notion that final blessedness consists in getting rid of consciousness—that the apotheosis of mind is a mindlessness. Mental energy behaves in the very opposite way to physical energy, which, according to the modern theory, is subject to an inherent degradation. Mind pushes upwards from plane to plane, gaining power and radiancy as it develops. The moral quality of conduct depends on the motive. Using motive in a rather broad sense to cover purposive disposition, even when it fades back into mere organic adaptation, we can construct a rough scale of the evolution of motive having three grades—unconscious, subconscious, and conscious. The first corresponds to the stage of animal instinct and need not occupy us here. By the time Man appears over the utmost edge of history he has already left the other animals a long way behind. Neanderthal man, for instance, to whom we are unwilling to concede

the title of *Homo sapiens*, nevertheless could chip a flint to a handy and beautiful shape, could light a fire, and buried his dead as if there was a future life in store for them. The second and third stages have an important bearing on the present discussion, since they stand respectively for those pre-ethical and ethical conditions which, morally speaking, constitute savagery and civilization. Subconscious morality is half-willed. A man's acts are truly willed only when he consciously selects his ends, and does it self-consciously, so that he establishes a kingdom of ends, as Kant would say, for the benefit of the self.

Our immediate object being simply to gauge the moral value of the uncivilized or primitive mode of human life, we can dismiss the subject of high-level or ethical living except so far as it supplies us with a standard whereby to judge the efforts of the savage to transcend his normal state of mind. This is always dim and groping. Its processes are uncritical. For the primitive man accepts his judgments about right and wrong at their face value. He can scarcely be said to make them, since he takes them as they come. Just as a child babbles in the words that his elders put into his mouth, so does the member of a primitive community follow the moral tradition of his folk without the slightest wish to change it for the better. Andrew Lang once composed the tale of Why-Why, the First Radical, to show how in palæolithic times a man of Lang's own tastes and upbringing might have perceived in respect to Stone-Age humanity that "manners they had none and their customs were beastly." The only portion of the story that has even a symbolic bearing on history is the conclusion, which relates how Why-Why was very promptly done to death by his fellows. The non-conformist or the conscientious objector is quite unknown among savages; and it is fair to say that savages remain such for this very reason. Hence, anyone who contemplates a primitive society from a certain distance has the illusion that it is stationary, just as if he were watching a so-called fixed star. For the last few centuries civilized society has been moving so fast that by contrast the old-world rate of progress seems

no advance at all. The further back one looks, the more incredibly slow is the pace. During the Ice Age the very glaciers went faster than man, and yet the comparison of one millennium with the next will always reveal a certain cultural creep.

The humblest savage has a culture of some sort, whereas no other animal has. Man has a social inheritance in the shape of a hoard of properties and precepts which accumulate, as it were, by themselves, whereas animals have only individual experience, including a little early training. Often a savage sees a good thing right under his nose and throws it away because he shies from the new thing. If some genius, bolder than the rest, exploits it for his own purposes with success, little intelligence on the part of the others is needed to copy his example. Thus fashion is the basic law of primitive culture. Moreover, fashions change, though nobody at the time is more than half aware of the fact. If they change, it will usually be for better or worse. Now a society strong in other ways can doubtless indulge in some bad habits without suffering greatly. Primitive folk exist on a very small margin of safety, so that a pernicious fashion soon weeds them out. Either Nature exterminates them or they succumb to some other enemy; the latter fate being preferable, since at the hands of such a taskmaster they may learn to change their habits before it is too late. Indeed, the more radical changes of custom observable in the primitive world seem mostly due to external contacts, and these for the most part were not gentle. Moral progress by means of self-education has hardly begun. An ethical morality is dynamic, whereas a pre-ethical or customary morality is inferior to it because it is inert.

Yet there are compensations. The higher morality is more experimental, and consequently exhibits a clashing of standards which is disturbing to those, always a majority, who need a bell-wether to lead their steps. These hesitate and are lost, so that under civilized conditions many are morally in a worse case than they would be if they lived in a primitive community. For in the latter everyone knows his station and its duties, and everyone is therefore disposed to play the

part expected of him. It would shock himself as much as the rest if he were to act unconventionally. Though morality always costs an effort, it needs less of that willed effort which feels like movement in the line of greatest resistance if one suffers merely in order to be respectable. Thus it is that to many who have lived in the midst of it—as, for instance, the naturalist, A. R. Wallace—savage society seems miraculously well-behaved. So it is, but in a passive and negative way, inasmuch as it is obsessed by a traditional set of habits which dominate it, the bad with the good. A man does the right thing for a positive reason, but the correct thing merely because it never strikes him that anybody could act otherwise.

So far it has been necessary to insist on the difference between savage and civilized morality taken each at its normal best. It is the part of every sound anthropologist to recognize it as a real difference in the social and mental level. Thus he can assure the administrator, on the one hand, that primitive folk may be trusted to be decent according to their own lights if left to manage for themselves. On the other hand, he must allow to the educator that, before they can acquire the spiritual freedom that goes with moral individuality, a long and careful training is required such as will develop their intelligence in all directions. This difference, then, exists, but it is not a hiatus, since it can be bridged. To make this latter point clear let us seek within savagery for the promise of a morality of the reflective type. It may well be that, when we look a little more closely into the régime of custom, its lack of conscious motive may wear another aspect. We may have to agree on the strength of the evidence that it is possible within certain narrow limits to be inarticulately conscious of certain ends that directly and obviously condition the good life. The real trouble caused by such inability to translate feelings into communicable thoughts may be not so much that it interferes with the intensiveness as with the extensiveness of the resulting morality. Consciousness of kin may be a duty that almost goes without saying, but consciousness of kind cannot develop out of it until it has been preached in plain language up and down the world.

Darwin somewhat quaintly observes in *The Descent of Man*: "The very idea of humanity, as far as I could observe, was new to most of the Guachos of the Pampas." No doubt it was. One wonders indeed in what possible terms the great naturalist could have presented the notion to such simple folk. But it by no means follows that the Guacho did not have dim feelings of humanity towards his own people, or even a dim feeling that he ought to have such feelings.

One may begin by trying to picture the simplest kind of domestic group known to the anthropologist. Though in the genetic sense the family must always consist of father, mother, and children, it by no means follows that this relationship should necessarily involve any permanent association on the part of the parents. On the contrary, effective symbiosis may in general have taken quite another line, as certainly happens in those frequent cases when the woman remains with her brethren, and the father of her children merely visits her temporarily, and it may even be furtively, from that other fireside when he usually squats and sleeps surrounded by his sisters and their progeny. Such extreme mother-right gives rise to a uni-parental family which without change of form enlarges into the matrilineal clan. Whether this is universally prior to the patrilineal clan is still an open question, but there can be little doubt that, typologically at all events, it is the more rudimentary type of organization.

The moral relations within such a narrow group, except for its somewhat casual amours, may be regarded as socially self-sufficient. Three major injunctions, two negative and one positive, form the nucleus of its moral code. There must be no incest, and no intestine murder, and the death of a kinsman must be avenged. What sanction, in the next place, lends to these laws that stringency which all the known facts show to be as nearly absolute as human laws can possess? Some theorists would account for it all in terms of instinct. But instinct is more or less automatic in its effect, whereas the very imperativeness of these ancient prescriptions shows that they stand in constant need of being enforced. The sanction is so much a matter of consciousness that it has a character at

once nascently legal and nascently religious. Thus, on the one hand, offenders are relentlessly punished by death or by excommunication. On the other hand, a belief in the sacredness of the common blood—the blood of the mothers—turns such offences into sins which, if they went unpunished, would bring universal ill-luck and ruin in their train.

For the little group concerned these commandments are quite explicit. They may even have explicit grounds, in so far as the thought of their violation provokes a sense of public injury and vague fears of misfortune. Among folk so closely huddled together it would be obvious that murderous quarrels about their own women or about anything else would render comfortable intercourse impossible; while, again, they could hardly weep together over their slain without fiercely clamouring to be revenged on the slayer. Yet one cannot argue that such group-life explained itself without the co-operation of the mind. The three laws in question are artificial creations of the human intelligence. Based on a one-sided notion of the family that ignored the father, they worked queerly from the first, and involved contradictory dispositions such as those severally needed for making courtships and vendettas with the next group. Considerable readjustment had to be made in their foreign policy before the various clans could coalesce into some sort of tribal union; and such a process, with all the mixing and discussion, must have wonderfully clarified their conceptions of what they wanted and of how it might best be obtained. We learn, for instance, from Spencer and Gillen that the Central Australians during some festal gathering of the usually scattered groups would hold informal councils at which the elders discussed matters touching the common welfare. Thereupon not only did they decide on executive details, but would likewise act freely in a legislative capacity, modifying even such fundamental principles as those of the marriage law. It is to be noted that the primitive conservative saved his face on these occasions by voting for a sort of progress backwards, the stock argument for a reform being that they must return to the customs of their ancestors of the Golden Age.

If further proof is wanted that moral law is not merely an echo of blind animal propensions, but stimulates the creativeness of man which to succeed must also risk failure in its vital experiments, we may consider the revolution in sentiment that takes place when mother-right gives way, as would seem to be the inevitable result of social evolution, to father-right of some kind. It is true that sometimes the new system is bi-parental, the mother's people never entirely relaxing their hold on the newly constituted family, which to a corresponding extent becomes a partnership, as when the children inherit the earnings of both parents or, more rarely and by a later development, are allowed to share in kin-property belonging to either side alike. Often, however, father-right is as lop-sided in its attitude towards conjugal equality as the more primitive system that knew no other symbol of social union except the mother's blood. Nor is this extreme type of patriarchalism confined to savages, for even civilized peoples such as the ancient Romans or modern Chinese have based their ethics and religion upon it. From a moral point of view the extraordinary interest of this radical change in the constitution of the family consists in the complete transference of the obligations of kin from one parent's group to the other's. To speak of the husband as a parent in this connection is perhaps to antedate the actual progress of human thought about the mystery of procreation. In Australia and New Guinea there are patrilineal peoples whose theory of genetics entirely overlooks the function of the male. The man, or rather his group, is owner of the woman and her offspring; yet of these she is still the sole vital source, apart from the supposed co-operation of certain reincarnating ancestral spirits. She would therefore still have every right to rank as high-priestess of the sacred blood, had not the religion of the blood-tie been in the meantime transformed. One can hardly suppose that some new metaphysic of transmigration was potent in itself to effect so mighty a change. Social convenience must be invoked to account for it. From this moment onwards the duties of respecting and protecting the blood were transferred, with a complete alteration of mean-

ing, to the kinsmen of the father. These in theory contributed no blood, but in fact transmitted the local name, with all the spiritual implications it might have—as, for instance, if it were totemic. Henceforth as before a man must marry out of his group, respect life within it, and be vengeful on its account; and yet he must now forget the mother's blood that was in him in order to respond to the mere magic of a name. Only metaphorically could he any longer claim to be "all one flesh" with his brethren, or at most could simulate a real blood-brotherhood by some rite of actual transfusion. In substance the meaning of the blood was gone. Nevertheless, through the shadow—that is, by means of the symbolism of the name—enough of the old force was transmitted to the new order to give it such a legal and moral sanction as would secure its stability. In place of a fact—for maternity is a fact, whereas paternity is an inference—a fiction must suffice as the formal basis of social fellowship. Here, then, as more than ever before was the opportunity of consciousness. So great a paradox called for some hard thinking. A sense-symbolism, almost a matter of sight and taste and smell, had been replaced by a word-symbolism such as is the chosen medium of all articulate thought.

A loose aggregation of inter-marrying clans kept apart by feuds, unless momentarily drawn together for common warfare or perhaps for the performance of religious ceremonies entailing a "truce of God," gradually knitted itself into closer confederation. North America, as contrasted with Australia, furnishes many examples of such a consolidated group-system, of which the best known is perhaps the famous Iroquois League of the Five Nations. At this point, at which more or less mobile bands of hunting folk are replaced by agricultural settlements densely massed together, the form of society changes. Wealth and war between them are now responsible for the appearance of aristocracy and a class-system. Correspondingly, there is more need than ever for intelligent government if the state is to be held together. This is the beginning of the Heroic Age, where the man of outstanding individuality, king or priest or the two in one has

a chance of reorganizing human life on a considerable scale and in the light of his own constructive ideas. This is the transition to barbarism and the dawn of civilization.

The progress may be studied from the inside by attending to the accompanying development of religion. The psychology of primitive man is revealed more clearly in his religion than in any other activity through which he can give expression to his intimate feelings and thoughts. No doubt one could with some difficulty distinguish a secular side to his festivity, fine art, literature, science, and philosophy; but such rudiments as would remain after they had been parted from whatever was of religious origin and import would scarcely be worth notice.

There are anthropological authorities of great distinction who disbelieve in this alliance. Sir Edward Tylor has declared that the connection between morality and religion is secondary and late. This is so hard to believe that one is tempted to treat the difficulty as one of words only; for some would prefer to strain the term "magic" so as to cover sacred rites not overtly addressed to a god rather than to give the word "religion" so broad a connotation. Otherwise, how deny the very early and truly primal relation of moral law to *tabu*? Yet *tabu* invariably has, if not a god, at any rate the unseen powers at its back. Human personality must presumably have developed in a corresponding degree before such deification can take place. Even backward folk such as the Australians can imagine a sort of Arch-mage, a magnified leader of the ceremonies, who presides over the initiation of the young men. It is he who imparts to them those manly virtues which the rites in their entirety, as their expressive symbolism shows, are designed to bring forth by a process of spiritual rebirth. It seems needless hair-splitting to concede that these savages have religion, and yet to deny it of other Australians who hold similar initiation ceremonies except for the fact that the regeneration is held to be effected without the aid of a god. Yet unless one either depreciates the claim of Daramulun of the Yuin to be what Andrew Lang would call "the high god of a low race," or else supplies the Arunta

with such a Supreme Being as the one for whom Sir Baldwin Spencer searched and, to check the contrary statement of a German missionary, searched again in vain, we are faced with the absurdity that what Sir James Fraser distinguishes as "the age of religion" and "the age of magic" are found together not only at the same moment, but at the same level of morality and general culture. While the theorists are deciding about a terminology, let us make religion something common to mankind.

Human religion regarded through the ages exhibits two tendencies which can be taken as constant: it feels deeply, and it thinks and speaks darkly. These are two sides of one fact, in that some intimation of the whole in the shape of a prophetic feeling must precondition any attempt to master its content bit by bit. Not only is this good logic, but history bears it out by showing that our race has always seen beyond the present. One can recognize the future lord of creation, for instance, in the totemite who without the slightest knowledge of how to domesticate animals or plants already imagines ways of controlling their multiplication. Something in him tells him that it can be done, and, though he fails at first, he tries again until he does it. Instead of passively acquiescing in the actual, as on the whole the mere animal might be said to do, Man with his high brain is always more inclined to treat it as the potential—to pretend, as it were, that it is more than it is. Religion does the same thing on the grandest scale, uniting all our minor efforts to elicit the promise from our surroundings. It refuses to take the world as it finds it, but reads into it a sort of infinite *plus*. M. Lévy-Bruhl has described the essential savage as a mystic, and the opposite of a mystic is apparently a positivist. It is highly doubtful, however, if there is a true positivist belonging to the human species; for the type is subhuman. There never was a more ardent mystic than the physicist who explores immensities ranging from the galactic system to the electrons constituting the atom. But a man's own mind-stuff is even more intriguing. To get more out of oneself is the ultimate purpose of the serious life. Hence religion, though it has always main-

tained a certain cosmological interest, is primarily concerned with the soul; for what we put into things is what we have first to get out of ourselves. Moral and spiritual evolution comes by willing the existence of the better intelligently and therefore freely, inasmuch as freedom is the preperception of destiny.

The savage's religion is essentially a self-stimulation, a means of stirring up the feelings to that pitch at which they fluctuate between extreme exaltation and extreme depression. He realizes that such transports act as a spiritual purge. Not only does the relatively civilized Ashanti defend occasional saturnalia as a method of rendering the heart "cool," but the rude black fellow of Australia, when he engages in one of those queer judicial duels at which the parties crack each others' crowns with alternate blows of a club, explains to the protesting white man "that always done, then angry no more."

This process of Man's biological history shows the human species to have avoided the specialization of functions that goes with fixed instincts, and consequently to have remained nervous and highly strung, because he is liable at decisive moments to be undecided about them. We need not think of the early savage as merely starting at shadows, though undoubtedly he did this, and it helped him to become an animist. The world contained plenty of unpleasantly real things. Primitive man improved his powers of attention by being naturally excited and then by making himself voluntarily more excited.

To the savage everything of outstanding interest, whether it be wonderfully useful, or wonderfully dangerous, or simply wonderfully perplexing, is both *mana* and *tabu*, but, primarily and positively, *mana*. It is "wonder-working" for good or evil; and that is why it is *tabu*, "not to be approached lightly." This wonder-working power is to be controlled by religion for the benefit of man, so that the good or divine kind may be separated out and preserved, while the bad or devilish kind is purged away and destroyed. Savage religion has this aim, and it proceeds to reach it by displaying what might

seem to the unthinking observer an unnecessary excitement over every event of any importance in the social or individual life. It exaggerates this importance, as it were, by treating the occurrence as if it were veritably a life-or-death affair. Good being everything that helps life, and bad being whatever leads to death, religion gives this tremendous significance to all such hopeful or fearful anticipations as may be awaked by any experience out of the common. Good without end and evil without end are always the ultimate implications of lucky and unlucky; and, to state the matter in its barest terms, these categories are fundamental for primitive religion. From fetish or totem to High God, all are, on a minimum definition of their function, so many means of securing luck. If, however, we substitute life for luck, we are nearer to their true meaning.

The emotional side of the savage cult of the sacred easily slips into extravagance because of its inability to distinguish the sacred from the unclean, the supernormal from the abnormal. The man who is in contact with *mana* hardly knows whether he is possessed by god or by devil, whether he is inspired or merely intoxicated. As far as the mere feeling goes it would seem that both conditions appear very much alike to the subject, so that some other criterion is required if the profitable kind of experience is to be distinguished from the other. Whether we call it sense, intuition, or reason, a faculty of judgment must be invoked. The difficulty is that the religious man is always standing on the very threshold of the unknown. All certain knowledge such as he may seem to have is behind him, and he is reaching forward to that which, being uncertain, is fraught with inevitable risk. Religion is experimental because life itself is so.

To proceed to an assessment of the intellectual factor in primitive religion, it has already been noted that religion always speaks and thinks darkly—that is, symbolically. Its reach must exceed its grasp. Now advanced religion, by means of a word-symbolism full of abstract terms, can construct a language of hope rich in suggestions of desirable things in excess of all human measures. The savage, on the

other hand, has a poor vocabulary and trusts mainly to concrete things for his images. One must not forget, when one sees a jumble of his crude emblems in the show-cases of some museum, that in their proper ceremonial setting they were the vehicles of faiths and aspirations none the less intense for being otherwise almost mute. Even if such material symbols were absent, the movements of the performers of some mimic dance are a kind of gesture-language. Yet words, though few, count enormously. Early gods are hardly more than names of power.

Primitive religion is subconscious, lacking in theology, and knowing itself almost entirely through its actions, together with the feelings aroused thereby. These actions are as many and various as those embraced in the social life. Every custom is a rite inasmuch as it is part of a sacred tradition. Religion becomes aware of its aims more especially in operations of a purely ceremonial character, in which the transcendental nature of the blessing sought is obvious. At the lowest level of cult, which from a doctrinal standpoint seems almost godless, it is hard to extract from the participants any clearer notion of their object than that somehow their hearts are made stronger. It is quite a mistake to suppose that they have material benefits in view and these only. They have found admission into an inner world which is in control of the outer. They may not yet have thought out the prepotency of the spiritual, but at least they have danced it out.

In this discussion the history of primitive mankind has been surveyed under the heads of social organization and religion. This is in accordance with the usual practice of anthropologists, and offers a method that can be made sufficiently comprehensive for our purpose, which is to consider human history as a moral evolution. Under the head of social organization can be grouped such subjects as economics, politics and law, and all that has to do with the material interests of mankind. Under the remaining head of religion falls in turn all that concerns our spiritual interests. Fine art and literature, science and philosophy belong to this division. Some might indeed think that science, which has provided so many

useful mechanical inventions, is on the side of the material interests; but this is a complete misunderstanding of its true aim, which is speculative. Greek mathematics and physics, for instance, were not the by-products of a utilitarian outlook on life, but were pure recreations of the mind. Indeed, these spiritual activities here classified under the general notion of religion may be termed recreative in their function, as contrasted with the material class, which may be distinguished as preservative. One must live before one can live well.

We alone of animals have culture and appear to owe it to religion as mother of the recreative arts which seek the welfare of the soul, while the preservative arts are merely providing the security of the body. One could almost speak of a lower deck and an upper deck morality, the one concerned with handling the vessel, the other with laying its course by the stars. Social organization develops plenty of common sense. But common sense does not try to see far ahead, being urged on from behind. Religion, on the other hand, ought to be thinking ahead all the time, since its business is to use a telescope as well as night and fog will allow. It must forfeit its place at the head of the recreative disciplines only if it were to forget to face the unknown, and instead look back over its shoulder to church history, which concerns the temporal rather than the spiritual side of life. The savage's religion is his University, the forcing-house of his higher culture, the seed-bed of his soul. No one can study the facts of his moral evolution without taking note of this. The pure anthropologist is primarily concerned with origins, and so considers this process mainly from what, in point of time, is the hither end. In our philosophizing on Man we have regarded it from the far end—teleologically. Viewing it in this way, as a pursuit of good, growing ever more conscious, though never perfectly so, can one say that a steady gain in good has come of human evolution? The answer seems to be, Yes.

THE LIVING MACHINE

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IN the trivial intercourse of daily life there are two subjects of conversation commoner than all others, weather and health. In the history of the growth of human knowledge also these two subjects have been from the beginning the principal incentives to enquiry. The dawn of physical science came with the observation and recording of times and seasons and their relations to the heavenly bodies. Astronomy and Mathematics came into existence in this way in days before the earliest records of history. By the habit of observation so formed, together with the invention of new methods for measuring, recording, collating and reasoning from the facts observed, men were led to the study of the laws of motion, of heat and light, of the nature and constitution of the atmosphere, of storms, tides, humidity and drought, electricity and magnetism. All that body of knowledge that has come to be included under the term physics can be traced back to a common origin in the ancient interest in the weather. The ancient interest in bodily health has been no less important. From the earliest times the wise concerning health rivalled in popular esteem those who constructed the first calendars, and from their endeavours there came forth in due course no less notable a progeny of sciences; chemistry, botany, zoology. To this day the art and practice of medicine grows and is nurtured by the scientific study of the human body. The science of physiology, which has grown out of this study, has always been the handmaid, or rather the foster-mother, of medicine.

But in spite of its origin in what so nearly concerns everyone, physiology can never be a popular science. Its relation

to medicine makes men fear the danger of a little knowledge. In popular astronomy there is no such danger. If astronomy can be a popular science and physiology cannot, it is not because the mental equipment necessary for understanding its achievements is nearer that of the average man. Everyone who is not an astronomer must stand in awe of the achievements of astronomy, and the more so the more deeply he has studied other branches of science. The seed from which physiology sprang may have been sown as long ago, but it was slow to germinate and hard to cultivate. It did not become fruitful until about 300 years ago. When astronomy germinated no one knows, but it has borne fruit for perhaps as many centuries as physiology has years. That does not mean that we today have become familiar with its methods of calculation, and the intricacy of the tackle that it uses, or even that we have any intimate knowledge of the precise problems with which it is engaged. Of all this the public is as ignorant as it is of the common occupations of the physiological laboratory. But from the earliest ages down to last week astronomy has set and kept men thinking upon the history of the world above and beyond the earth on which they live: and these regions are a favourite field for the imagination of every reflecting person.

Physiology, too, has spread its borders far beyond the study with which it began. There has been no choice in the matter. It is true that nearly all who have worked in physiology, if they have not actually practised medicine, set out in the first instance with that intention. Many of the activities of the human body, the working of which they had to get to understand, are so closely similar to those of simpler animals, some essentially the same as those of plants, that the opportunity and the hope of investigating them with success is far greater if these simpler types are studied in comparison with the processes of life in man. Much that is relevant and of value in the physiology of man has been learnt from the study of organisms as far removed as the yeast plant, and enquiry, the ultimate motive of which can be traced back to the needs of the physician, will not rest until all has been

learnt that can be learnt of the activities by which all forms of life maintain their living existence.

Direct experimentation on man is rarely possible. When it is it is usually based on knowledge previously gained from the experimental study of other species, in which similar problems present themselves uncomplicated by influences which confuse the picture in man. Without such experiments little progress could have been made. The advance of medicine is delayed by limiting investigations to its immediate needs.

Physiology now embraces all those chapters of biology which deal with the contributions made by the different parts of an organism to the well-being of the whole, to the maintenance and fulfilment of its life: and since an organism may be a single cell and every organism starts life as a single cell, the study of the contributions that the parts and components of a cell make to its well-being is logically the starting point of physiology. The largest animal cells rarely exceed a diameter of 1/250th of an inch, and the average dimension is less than a tenth of that. The study of the parts of which they are composed, the anatomy of cells or cytology, is therefore a microscopical science, and the physiology of the cell has also to be microscopical except where it is possible to study the properties and activities of large numbers of identical cells free from mixture with other varieties. But we cannot stop at the study of structures within the cell recognizable under the microscope. Ultimately the parts of which a cell is composed are the molecules of the various chemical substances found in it. The dimensions of the largest molecules are less than 1/1,000th of the dimensions of a small cell. Can we learn anything of the contribution to the fulfilment of the cell's life made by any of the kinds of molecules found in it?

The materials of which living cells, both animal and vegetable, are composed can be resolved completely into elements that are among the commonest of those that occur in matter which exhibits none of the phenomena of life. But in the substances obtained from cells the atoms of these ele-

ments are arranged in molecular configurations of extreme complexity. Is it the peculiar complexity of these arrangements of atoms that confers on the common elements the powers exhibited in living cells, which are composed entirely of these elements? If so, physiology ultimately resolves itself into a special form of chemistry, for chemistry is the science which defines the ways in which atoms of the elements arrange themselves and the properties exhibited by each arrangement.

Perishability is one of the properties of the material of which a living cell is composed. Not only must a cell ultimately die, it is continually perishing as long as it remains alive, but the loss of substance which it thus suffers it as continually makes good by the assimilation of foreign material, food, which it transforms into material similar to that which perishes. As fast as the substance of the living cell decays it is renewed; or even faster; for it may grow. Growth, however, is only an incident in the life of a cell or of an organism; the cell or organism does not cease to live when it ceases to grow, it merely strikes a balance between the rate at which new living material is formed and that at which the old breaks down. This assimilative transformation of unorganized matter by the substance of the cell is a phenomenon inseparable from life and nothing like it can be observed otherwise in nature: it is one of the riddles of biology. Is this power a property conferred on the cell by the peculiar constitution of the chemical substances of which it is composed? If it is, the ultimate fundamental problem of physiology is to find out all that can be known of the configurations and arrangements of material elements in which it resides. Sooner or later these arrangements are dissolved and the elements taking part in them turn to dust again. How is it that the frail, perishable dispositions of the elements of dust are during life daily renewed and maintained? Chemical investigation of the composition of cells has revealed substances of an almost infinite complexity and variety that only living cells can make; in the constitution of many of these substances it has made clear certain chemically definable

features, and in the case of others has also made clear certain powers that reside in them by which the chemical behaviour of adjacent foreign material can be altered. These powers are known to have great influence on the course of chemical events peculiar to living cells and to contribute to the fulfilment of the life of the cells. But this throws no light upon the way in which what is simple and lifeless is assimilated by what is alive and then is endowed with life. By the time the substances which can be obtained from living cells can be analysed life is gone from them, and even when the baffling perplexity of their nature has been clarified, what they were when they shared in and contributed to the life of the cell and why they were different then may be as obscure as ever. No one can say how much, if any, light even complete clarity as to all details in the chemical constitution of proteins and the other mysterious components of cells will throw upon the processes by which the living material builds itself up anew from the simpler materials which are its food, and continues to do so so long as it lives and when it ceases dies. It may not be logical to expect that what can live should reveal its nature through analysis of what is dead. But none the less everything that can be learnt of the nature of the material that has served it is relevant for the study of its powers. Physiology has waited on anatomy from the beginning. It waits now in hopeful but uncertain expectancy upon the chemical anatomy of the cell.

This implies two things. First, the chemical configuration and internal structure of the molecules which only living cells can produce and of which, by the time any analysis is possible, they appear to consist; and secondly, far more difficult even than this, the way in which the different kinds of molecules link up to form the internal fabric of the cell.

Physiology as usually taught and studied is mainly concerned with higher animals. All the parts of which the body of a man or other animal is composed are themselves composed of cells or of material investing cells that has been deposited by them; and all the cells have been formed originally from a single egg-cell. The egg-cell as it grows

divides into two, each half again into two, and so on, till in the fully grown man there are many billions of cells. In his blood alone, of which he has about 5 litres, each litre contains 5 billion red blood corpuscles (5×10^{12}). The first cells formed by the division of the egg-cell are alike, but as division proceeds differences begin to appear in different parts of the cluster of cells and the differences become more and more pronounced. The different parts acquire peculiarities of structure and of grouping that enable them to serve the rest of the cluster in different ways so that the cluster becomes an organism composed of different organs.

A single cell may be a self-sufficient organism; it is then so constituted that it can provide for its needs by taking up food and oxygen directly from, and discharging waste directly into, the water with which it is in contact. In so doing it avails itself of the violent commotion, kinetic activity, of molecules or ions dissolved in the liquid state or freely dispersed through space in the gaseous state. It has no fellows to which it can relegate any of the duties.

In a man's body every cell has the same common primitive needs: it must have food, as a fire must have fuel; as a fire, too, it must have oxygen and it must not be choked by the fumes and ashes of its own burning. But it is only a few of the cells in his body that have direct access to the food he eats. Even of those over which the food passes, in his mouth, throat, stomach, and intestines, it is only those in the intestine that actually take it up directly. The cells lining the surface of the intestine do so and hand on what they themselves do not use to the blood that streams in fine capillary tubes close by them. All other cells than these are entirely dependent on the blood for their supply of food. So, too, with the oxygen that every cell in the body must have; this, too, has to be conveyed by the blood, and it is only in the innermost parts of the lungs that the air is brought into sufficiently close relations with the blood for the oxygen to be taken up by it. If the air in the lungs is not constantly renewed by the movements of the chest, and the blood kept circulating through the capillaries of the lungs in the closest

relation to this air, the fact that the body is surrounded by air containing oxygen is of no avail; the body is unable to get oxygen from it and in three minutes the man is dead. The removal of waste similarly can only be done by the circulating blood. Cells on the surfaces of the body may be in a position to shed some of their refuse where it can do no harm and be rubbed or washed away; but the vast majority of the cells in the body depend entirely upon the circulating blood for this primitive service. There are certain parts of the body where the blood can unload this refuse and purify itself; in the lungs it emits carbonic acid gas which can escape with the air expelled from the chest; in the kidneys substances dissolved in water can escape and to a very much less extent on the skin or the internal surface of the bowel. If a man's kidneys cease to act he dies in four or five days.

For all these essential services rendered by the circulating blood all vertebrates depend upon a machinery that in its general plan is broadly the same. The blood flows in the finest capillary tubes, about 1/3,000th of an inch in bore, close past the cells that make use of it. It is supplied to these tubes under pressure by small arterioles, the walls of which contain muscle; this muscle, by its contraction or relaxation, controls the amount dispensed. The arterioles lead from a system of arteries, tubular branches of the great vessels fed by the heart itself, which form a distensible elastic reservoir filled with blood under pressure; much as the bag of a bagpipes forms a reservoir of air under pressure that escapes through the drones or the keys of the chanter when the pipes are playing. The bag is kept filled by the piper's expiratory muscles; the arteries by the muscular walls of the pump-like valved ventricles of the heart. As long as there have been vertebrate animals on the earth this sort of machinery has been perfected and in general use, and even long before that many features of this system were in existence in invertebrates. For millions of centuries this system has worked, and survived because it worked. How long it took to be sketched out before that cannot be guessed.

Cells of many kinds are used in its construction; quickly

acting muscle cells for the heart; for the arterioles more slowly acting muscle cells capable of remaining in action for hours at a time; cells that secrete a web of fibres investing the tubes in due measure according to the strains to which their walls are exposed from the pressure of blood within them; here fibres that lie slack around the undistended vessel take up the slack as the vessel distends but then hold fast and do not give, acting much as the net about an inflated balloon; there fibres of another kind, with no slack, that give under strain only to pull things back into place again by their elasticity as the strain passes; each kind of fibre appearing in due amount as required and where required, formed in response to the strains felt by the cells which secrete them, maintained so long as the strains persistently recur, wasting and disappearing when they cease; cells again of a totally different kind, which line every part of the tubular system in which the blood flows, a smooth sheet of the thinnest tessellated cells which, appropriate in many other ways, have also mysterious properties by virtue of which the blood that clots so easily when it escapes remains fluid indefinitely when in contact only with them; these same cells in the capillaries, the only part of the vascular system in which the real business of the blood is transacted, forming the only retaining wall for the blood stream, a retaining wall not more than 1/25,000th of an inch thick, so thin that what all the other cells of the body need of the blood can pass through without let or hindrance and yet the corpuscles and even large protein molecules be kept in their proper place within; in fact, everywhere in the circulatory system, as throughout the body, cells, all of one common parentage, which nevertheless in each part have those particular properties and powers which fit them for the work there in hand, properties and powers called into existence by the influences to which the cells are there exposed. It is not difficult even for one who has not studied the subject in detail to appreciate how far we are from understanding the adjustments of their chemical anatomy involved.

Moreover, the needs of different parts of the body are dif-

ferent at different times. When a man is asleep his muscles are at rest. They will, therefore, not need oxygen or fuel in anything like the same quantity as when he is actively engaged in laborious occupations. His eyes are shut; when he is awake and they are in use they may evoke through other parts of the nervous system many different kinds and degrees of activity which are not evoked when he is asleep. For each kind and degree the machinery on which the amount of blood dispensed to each part of the body depends is adjusted so that the needs of the moment in each part are met by a corresponding supply of blood. As the need passes the supply is reduced again, with due regard to economizing the energy of the heart. In a given emergency a man may, without taking thought, spring into action and do in the exactly appropriate way something that requires all the energy that he can command. He may put every ounce of his strength into what he does; but every ounce means in the account rendered so much more oxygen to be delivered by the blood, so much more energy expended at the cost of food to be brought by the blood, so much more carbonic acid gas produced to be carried by the blood to the lungs. It is clear that there must be much more for the blood to do in working muscles; we know, in fact, it may be a hundred times as much. It would be extravagant if the ordinary service supplied blood so freely that it covered even exceptional demands such as these. How is the maximum of efficiency to be combined with the maximum economy? The muscles with which a man works his limbs consist of parallel contractile fibres. In a section across these fibres, each of which is a 1/1,000th of an inch or so in diameter, it may be seen under the microscope that each fibre has running parallel with it, and therefore also cut across, a number of capillary bloodvessels, visible as dots at two, three or more points on its circumference. To make them visible a little indian ink can be injected into the circulation of an anæsthetized animal before death. Any bloodvessel containing blood will then appear as a dark spot. If the muscle examined was at rest capillaries will show up only here and there as dark specks; for most of the muscle

fibres none may be in evidence. If the muscle was in action immediately before the animal's death ten, twenty, or fifty times as many capillaries may be seen and most of them much more fully distended with blood. The capillaries in certain parts of a living frog can be watched under the microscope and the blood seen flowing through them. They can be seen to open for a time and then close up again, so that they take turns, when things are quiet, at letting blood through and only a few are open at any one moment. But as the observations on muscle show, they can all be opened when necessary at the same time and then opened much more widely so that blood races through them in much greater quantity. To make this possible the muscle in the walls of the appropriate arterioles relaxes at the same time so as to release more blood from the arterial reservoir. When the active organ in which this is happening is a small one or the movements to be carried out involve only a few small muscles, as in knitting, writing or quiet talking, the depletion of the reservoir is almost negligible and no further adjustments are necessary. But in severe muscular exertions, when nearly all the muscles of the limbs and trunk are involved, contracting and relaxing rapidly and repeatedly, the number of arterioles that dilate and of capillaries they have to fill may become very large; the reservoir then is in danger of being seriously depleted so that the pressure in it would be insufficient to drive the blood through the minute tubes. But when things are working properly nothing of the kind occurs. To begin with, as many as possible of the other outlets from the reservoir are shut down, because the arterioles to parts which at the moment need not be working contract; blood is then diverted from them to parts where it is needed in greater amount. But much more important than this, the blood rushing through the muscles in vastly greater quantity than before is hurried back to the heart much more quickly, and the heart is a pump so made that the fuller it is the more powerfully it works, and so controlled by the nervous system that the more rapidly it fills the more frequent its stroke. The rate at which the arterial reservoir is filled by

the heart is thus increased in proportion as the rate at which the blood is allowed to escape from the reservoir rises, and the net result may be that the head of pressure in it is actually higher, not lower, than before, and the amount of blood put into circulation by the heart in a minutue may go up from perhaps five or six litres a minute to thirty or forty. This final result is attained, then, by a quicker return of blood to the heart and a correspondingly quicker and stronger action of the heart. The quicker return is mainly accounted for in two ways. First, the veins by which it has to be conveyed are compressed as the contracting muscles swell and harden against them, and rapidly filled again as these muscles a moment later relax to let their opponents in their turn contract in all such alternating movements as swimming, rowing and running. In the veins thus alternately compressed and allowed to fill there are valves which, as Harvey first made clear, ensure that no blood is pressed in the wrong direction, all must go towards the heart. Secondly, the carbonic acid, as well as sometimes other acid, produced by the working muscle acts on the part of the brain that works the muscles used in respiration and causes much more vigorous movements of the chest. The greater expansion of the chest not only draws more air into the lungs through the windpipe, but, since the heart is in the chest no less than the lungs, draws blood into the heart from the veins on their way to the heart from other parts of the body. At the same time the diaphragm between the chest and the abdomen, as it descends in inspiration, enlarging the capacity of the chest and diminishing that of the abdomen, forces blood from the abdominal veins up into the heart. The muscles, by going into action, themselves set in motion machinery for promoting a much more rapid flow of blood to the heart, and so increase their own supply.

Similarly, the quicker return of blood to the heart brings into operation a property of the muscle of which its walls are composed, namely, that when more stretched it contracts with greater vigour than when less stretched. A full heart responds to the increased demand made upon it and expels

more blood at each stroke. This property of the cardiac muscle operates within fairly wide limits, but not without limit. An over-full heart may be embarrassed by too great distention. Over-filling of the heart, however, is provided against by yet another adjustment. Nerves in the part of the heart which receives the blood from the veins are stimulated when this part of the heart is stretched. These nerves act on the cells in the brain that control the rate and force of the heart beat, and release it from the restraining influence which these cells otherwise exert. As a result of this it is quickened and beats perhaps more than twice as frequently as before. At the same time, since the blood is returning much more than twice as rapidly as before, it fills up even in the shortened intervals between its beats much fuller than before. Its beat consequently is, for the reason mentioned already, at the same time stronger, and its total output per minute may be five or six times what it was.

All this is one of the commonplaces of physiology, but there is no better illustration of the way in which many different parts and organs of the body are brought into action together, each doing what it can and must, to increase the efficiency of the whole. Even in present-day civilized conditions a man's life often may depend on his power to make a great and sustained effort; and it must be remembered that his power of doing so was acquired long before there was any question of civilization, when this power had to be called into play daily and hourly if he was to survive at all. Nor are the reactions involved even peculiar to the human body; the adjustments are the same in other mammals, and knowledge of them has actually in the first instance been obtained from experiments on rabbits, dogs and cats, many of them even from experiments on animals as remote from man as frogs, much older than any mammals.

In this combination or co-ordination of the activities of different parts for a common end, the several parts are brought into action at the appropriate moment largely through the nervous system, which is the supreme co-ordinating mechanism of the body. The whole outbreak of

activity may be started by something seen or heard which sets the brain to work; the brain, acting through other parts of the nervous system, brings the appropriate muscles and combinations of muscles into action at the right moments and with the right degree of force. The control of the escape of blood from the arterial reservoir, and the control of the rate and force of the heart beat which fills the reservoir, is effected by the nervous system, as is also the rate and depth of respiratory movements. But in addition to that, substances formed in active cells may act as co-ordinating chemical stimulants on other cells to which they are conveyed by the blood or which they reach by diffusion in the liquid which fills the interstices between cells everywhere in the body. The opening up of the capillaries running along the muscle fibres is effected by substances produced in the muscle fibres when they contract. The same substances, or some of them, conveyed by the blood to the brain increase the activity of the part that rhythmically works the respiratory muscles. An important part is played, too, by a substance produced in the little suprarenal glands where there are cells that have, so far as we know, nothing else to do but make the substance adrenaline. This substance tones up the influence of a part of the nervous system which is specially concerned with the heart and arterioles, but also with most viscera, and so the heart is quickened and invigorated, some arterioles are dilated and equally appropriately others constricted, the spleen is made to yield some of its reserve of blood, the activities of the stomach and intestine suspended; in short, everything throughout the body is so set as to give the working muscles the best chance of showing what they can do.

In every chapter of the physiology of higher animals and man a story is found as amazing as that which the study of the circulation presents: cells, all of them derived from one common parent cell taking up as the organism grows definite positions, the same in each generation; there developing special properties by virtue of which each kind of cell can co-operate with its fellows in its own specific way for

their common well-being, and each adjusting its activity appropriately to the changing needs of the whole society of which it is a member.

Just as we often speak of the material in which the phenomena of life are exhibited as living matter, we may with as good reason speak of an organism as a living machine. A machine is constructed so as to work in a certain way; its design may provide automatic adaptation to changes in the conditions in which it may have to work. Gears may be changed automatically; a loom may stop itself while it repairs a broken thread; a chronometer compensate for changes in temperature. That has all been thought out beforehand in the design of its construction.

These are figures of speech. To speak of living matter is to slur over the fact that all other matter is lifeless, dead as a stone; this is matter that is alive. Recognition that the elements in it are among the commonest components of the lifeless earth and air merely emphasizes that the mystery of why it is alive has not been fathomed. Biochemistry has a high-sounding name. But chemistry, the science that defines the groupings into which atoms fall and the properties those groupings confer on lifeless matter, when it assumes this name does not claim that it can explain the chemistry of life. If anyone is led by all he hears of the triumphs of biochemistry to imagine that that problem has been solved it would be a case of the blind not knowing that they were being led by the blind. It is not that the biochemists themselves think they can see. They do not pretend to define the chemical constitution of the material of the germ cell, a speck of matter too small to be seen without a microscope, which in appropriate surroundings will produce a progeny of a hundred different types of cells, millions or billions of each kind so distributed and with such properties that the whole organized society which that progeny forms may reproduce a likeness of the parent organism from which the germ cell sprang. Not merely an anatomical likeness, the same number of fingers and toes and ribs, jointed in the same places and in the same ways, nor one confined to material resem-

blances, colour of eyes or hair, but a functional likeness. A baby does not have to be taught to crawl or sneeze or smile. A child may grow to resemble a grandparent or an uncle it never saw in quality of voice and intonation, facial expression, carriage and movements. Something in the chemical constitution of that microscopic speck of matter has directed the growth and grouping of its progeny of cells, nerve cells, muscle cells, bone cells and the rest, so exactly that the whole resulting organization walks, talks and laughs in recognizably the same way as did the organization that grew from another such speck and became the child's grandfather or uncle, differently from others of different parentage.

So, too, therefore, when we speak of the machinery of the animal body, of its organs of circulation or respiration, it is a form of speech that may be misconstrued. It does not imply that the design of its structure and every readjustment of which it is capable is once for all provided for in the original, rigidly according to specifications. In course of time living organisms can change their design, their structure and function, so that they may meet changes in their circumstances that they have never had to meet before. The machinery is alive and readapts its own design according to changes in its circumstances.

When a type of organ is common to different divisions of the animal kingdom and not found in the rest, it is probable that these divisions that have it have a common ancestry. It is easier to suppose such a common ancestry than to suppose that that type or organ has appeared independently at different times in different classes of animals. The common features of the spinal columns of all vertebrates are thus taken to mean that all vertebrates have common ancestors; and the peculiarities in the composition of their blood common to them all point to the common ancestors having lived as marine animals at an early period in the history of the earth. The special properties of the nerve cell point to a common ancestry not only for all vertebrates but for many other large classes of animals as well. From very early days in the history of life the organ which in its perfected form

has given man his pre-eminence has been in the service of animals. But the nervous system has modified its design in man so as to react in many ways in which in the snail it does not, and in the snail in many ways in which it does not in man. Throughout the evolution of higher types the living machinery has become sensitive to more and more factors in its environment and readjusted itself to changing circumstances of climate, food supply and competition. All this has been done as part of the natural reaction of what is alive, not deliberately as the result of forethought or conscious volition. The evidence for such evolution is, of course, mainly inferential, but it is strong. Physiology looks forward to the day when experimental evidence may be obtained from its study of living cells and their chemical anatomy which will make it possible to understand how such a living mechanism as that by which the blood is circulated in a man's body has been perfected in the performance of the service which it renders. Most of the experiments it has devised hitherto have been planned to show how the machine in any particular species works. All of them have revealed an amazingly appropriate adaptability to the changes that constantly recur in the needs of the individual. But it is on the lookout for methods by which it may learn how the adaptations of design that are characteristic for any species are brought about.

Such investigations must entail the study not only of individual animals, but of long series of generations. A beginning was made in Pavlov's well-known experiments in which he showed that a dog's experience may bring into existence a reaction which otherwise does not occur in a dog. Its salivary glands are normally set in action by nerve cells in its brain, which in their turn are set in action normally by nerve cells connected with its nose or mouth or eye, which react to the smell, taste or sight of appetizing food. But other nerve cells connected with its skin or ear, capable of giving rise to sensations of touch or hearing, may acquire the power of activating the cells that start salivation if some particular one of these sensations is set up by, for instance, the

regular use of a bell at feeding time. At first the sound of the bell by itself has no effect on the salivary glands. But after it has been sounded daily when the animal is fed a time comes when the sound of the bell by itself is as effective in starting a flow of saliva as the smell or taste of the food it enjoys. The nerves of smell and taste are connected up in all dogs with the cells that start salivation, but in the dogs used in these experiments it has been possible to establish a similar connection also for nerves of hearing or touch, a connection which did not exist before. A new anatomical structure has been brought into existence as a result of a change in the circumstances of the animal's life. Pavlov, moreover, thought at one time that he had evidence to show that in succeeding generations of dogs the sound of the bell became effective in a much shorter time; but he decided later that on this point the evidence he had obtained was not satisfactory. More recently, however, Macdougall has shown convincingly that rats respond in a certain way to a warning light at the third or fourth trial in the twentieth generation, whereas twenty generations back the response could not be obtained till after two hundred trials. Apparently the experience not only of the individual but of its ancestors can cause nerve cells to grow in a particular way in which otherwise they do not.

A new function involving a change in the design of nervous machinery has been brought into existence as the result of a reaction of the living machine to external events. This particular reaction does not affect the chances of survival of the dog; there is nothing gained by it; it is just superfluity of vitality. But so long as the change in external circumstances persists the reaction persists; and if it were a useful reaction it would make for survival; moreover, if Macdougall's experiments stand, the new machinery would become part of the machinery of the species.

It is not, therefore, only the extraordinary complexity and extraordinary appropriateness of design in living machinery that physiology has to study; it has also to observe and explore the ways in which the design grows and develops.

The secretion of saliva is not a voluntary act: it takes place without the dog knowing anything about it. One of the reasons why it is difficult for anyone who has not studied physiology to understand how that study can affect his outlook on the world is perhaps this. He knows that it deals with what goes on in his body. Most of what he knows about this to start with is that of which he is conscious. He is accustomed to manage his own life and to decide how he will occupy himself from minute to minute throughout its course. He has to learn how much more there is of what goes on in him of which he has no conscious knowledge, and how much more appropriately this is done as a rule than what he himself consciously plans. It is only a very small part of the activities even of his brain in which he is, so to speak, consulted. Far the larger part is just the working of the living machinery that has cunningly adjusted itself to the experience of his race and species, and of ancestors far further back than his species or any living species can be traced. Every posture is arranged and appropriately maintained, every simple movement is carried out for him by chains of cooperating cells with a precision and economy in which consciousness has nothing to say. The machinery has been perfected because it is alive, not because it is conscious of what it has to do. Even in the skill of an accomplished singer or billiard player there is comparatively little that is due to conscious volition. Otherwise it would be far easier for such people to impart the mystery of their skill. Consciousness is for psychology to study; it is outside the province of physiology. Physiology regards consciousness merely as one might regard the impresario who arranges the programme. What it is interested in is the artist and the music he draws from his instrument. In the skill of an artist it recognizes a self-adjusting living machinery, such as is found in whatever is alive, in which consciousness plays as much or as little part as it does in the easy certainty with which a cat jumps on to a wall, in the gambols of a school of porpoises, or in the flight of gulls and swallows. Consciousness makes fools of us all; for there is no folly greater than to suppose that what

we know is all there is to know. That folly is the first thing a schooling in physiology corrects.

But few have time or opportunity to attend this school. What the majority of men can pick up of physiology is seldom more than a third-hand familiarity with some of its terms. They learn to talk, for instance, of reflex action, which they are content to define as an unconscious act of a man or animal, a definition which conveys almost nothing but complete ignorance of what a reflex really is. It is common to talk with easy assurance of a reflex as if it were some sort of clockwork mechanism that might shortly be purchaseable for a few pence at a toyshop, as if the recognition of the part played by reflexes in ordinary human life had cleared up all that is mysterious in it except perhaps consciousness.

A reflex implies, to begin with, a nerve cell from which has grown out a projecting filament or feeler to a distance generally out of all proportion with the ordinary dimensions of cells. Animal cells rarely measure more than 1/250th of an inch in any diameter; this feeler may in a man grow out to a distance of three or four feet from the cell of which it is functionally and by origin a part. Stripped of the investing sheath which other cells deposit around it, it is never more than 1/5,000th of an inch thick. Its length, therefore, may be 200,000 times its diameter; magnified to the thickness of a piece of sewing thread, say 1/50th of an inch, its length would then be anything up to a hundred yards. The direction in which it has grown, and the connections which it and its ramifications have established, are those which have been characteristic of a similar cell in the man's ancestors for thousands of generations. At the extremity of this feeler or of one of the still finer spreading filaments into which it frays out before it finally terminates, some displacement, it may be of only an adjacent molecule, or atom or part of an atom in a molecule, brought about by something it may be as impalpable as light, sets up a change which is flashed along the whole length of the filament up to its parent cell. The change which passes along the filament

travels at the rate of about a hundred yards a second, but what exactly it consists in is still not understood. It is called a nerve impulse, appropriately enough as the name conveys nothing in particular; nothing like it is known. This impulse, or more often a rapid series of impulses, reaches the cell and passes on along another filament that has grown from the cell in the direction of the mass of nerve cells that constitutes the spinal cord and brain. Here this filament frays out into a number of finer fibrils each of which ends in the immediate neighbourhood of the feelers of another nerve cell, one fibril those of one cell, others those of others. In these feelers the nerve impulse can awake on its arrival a similar impulse, which is then in its turn flashed to the furthest point of the filament thrown out by this cell; and so on, it may be through a whole concatenation of cells, all of them within the brain or spinal cord. Sooner or later the feelers of cells are affected from which filaments pass out and convey the impulse in them to cells of another kind, muscle cells or gland cells, and then the appropriate activity of movement or secretion is set up; for the nerve impulse can do this too. Every section of the route travelled by the reflex has to be composed of "living matter" keeping itself alive, taking up oxygen and recovering from the disturbances that pass along it; every molecule or fragment of a molecule, along a path that may possibly measure some feet in length, must know its place and observe its station. Such is the mechanism of a reflex. Physiology has rendered no great service if it has taught people to talk glibly of a reflex as if it were some simple clockwork contrivance.

Most people have heard something of astonishing achievements of biochemistry in tracking down, isolating or even finally manufacturing substances which are normally produced by cells here or there in the body and which exert extraordinary powers in directing development or influencing conduct. In the proportions in which they are normally produced they contribute to the balance of influences which results in normal growth of body and mind; in abnormal proportions they lead to loss of balance. Or they may have

heard how other disturbances of this balance have been traced to excess or deficiency of some factor in the environment, including in this expression food, the components of sunlight and so forth. Even when such information is perfectly correct it may often be so novel and surprising that they are in danger of losing their sense of perspective, unless their study of physiology has been broader and deeper than with the majority it can be. They are apt to forget that one of the things the investigator in pursuit of new knowledge has to do is to exert his imagination and catch at and test even the faintest clue. It is the investigator's business to make the utmost possible use of ideas in which only a small fragment of the whole truth may be contained. The suspicion with which probably most people regard the specialist is not altogether unhealthy. There is always the danger that his disciples, if not the specialist himself, may become prigs; ignore, that is, what they don't know and exaggerate the significance of what they do. New knowledge in itself is a factor in the environment of human life to which adjustments have to be made, and in all probability the best part of the adjustment will not be the result of conscious planning. Life has looked after itself for hundreds of millions of years without the assistance of what can be recognized as consciousness, done it extraordinarily well and continues to do so still.

It should not be regarded as a trespass on to other fields than that of physiology to refer to a faculty of the human body which history can prove to be in process of development today. The history of music goes back, no doubt, to the earliest historical times, yet the material for that history is so scanty that it makes but a small chapter in the history of civilization. For the physiologist the two outstanding phenomena in it are the development in the Greeks of a sense of rhythm that has not been approached by any civilized people since, and the growth of the sense of harmony in the last few centuries.

The Greek sensibility to rhythm in all its richness and diversity was fortunately developed before facilities for writ

ing. It could not have been developed after the invention of the printing press. The written records of literature dethroned the ear and put an end to the growth of the sense of rhythm. The record of rhythmic phrase was for the Greeks in the mind, played upon by sensations of rhythmical sound and sensations of rhythmical movement. The play of these sensations in the living nerve cells brought into being a considerable part of man's brain. It produced the faculties that have found expression in poetry, besides the music of three thousand years since this sensibility attained its perfection.

In our own day the growth of the sense of harmony is the most striking example of the physiological process of unconscious growth and perfection of a functioning organ. Quite recently—perhaps in the 15th century—the third was a discord and the octave and the fifth the only tolerable harmonics. The ear has gradually quite unconsciously recognized since then many other harmonics that may accompany a particular note on a particular instrument, and has taught responsive reflexes to play with what it has come to hear. This growth of harmonic sense owes little if anything to deliberate scientific planning.

It is like the processes by which we acquired ages ago the system on which we depend for the circulation of blood with its myriads of corpuscles bringing oxygen and food right up to every cell in our bodies, a system which in essentials was perfected for us when there was nothing higher than a fish inhabiting the earth; it is like the processes still much further back in the history of life when nerve cells were learning to make themselves useful to the community of which they form a part, an instance of the self-perfecting powers of 'living machinery.'

Life is something much bigger than human consciousness.

And what does it all mean for us? Can we do no more than exclaim, 'No wonder if with such antecedents half the human race, or all of it, still has traits that it shares with the shark, the wolf, and the pig'? Does it mean no more than that? Is it no wonder that from this ancestry in recent

times have sprung the glorious company of the poets, Homer and St. Francis, Hans Andersen and all the goodly fellowship of the prophets, the noble army of martyrs, and only yesterday the unaccountable inspiration of music? All this has to be remembered and is implied when we speak of "living matter."

PSYCHOLOGY AND BEYOND

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THE question: What is the Outlook of Science? raises the prior question: How is 'science' to be defined or characterized?

It may be said: Surely this or that science may be defined in terms of its subject-matter; for example, mathematics, geometry; physics, chemistry; biology, psychology. Here, apart from some overlap, the question is: What is the aim of this or that scientific inquirer? Taking, for example, two salient cases, we may ask: What is the physicist's aim? What is the aim of the psychologist? If we can catch them at work, each in his own chosen field of inquiry, we may be able to judge for ourselves.

The stress may then fall on scientific method. Scientific method is the means by which the physicist, the psychologist, or other man of science, attains the aim which is the goal of his inquiry. But what is this goal? It may be to render an account of what happens on some occasion and on all like occasions in physical terms, or in psychological terms, within a 'closed system' of events or occurrences, physical on the one hand, mental on the other hand.

Can this be done in physics and in psychology respectively? It suffices to say that it has been attempted.

There are those who contend that, on the physical side of the account, this attempt has been successful. It is clear that, apart from some apprehending mind, the physical world is nowise apprehended. But it does not follow that, apart from any apprehending mind, the course of physical events is not there all the time to be apprehended on suitable occasions. This question, therefore, does arise: Is the current course of physical events the same in all respects and on all

occasions, whether it be apprehended by some mind or not? The physicist may claim that it is; otherwise, he may say, there would be no closed system of physical events.

But when we turn to apprehending and to what is apprehended on the part of some mind—when we turn to knowing and what is known—*this* comes, it may be said, within the purview of psychology. We pass outside the boundary line which circumscribes physics.

On these terms the psychologist may seek to make out a case for a closed system of mind with which it is his special province to deal. In what follows an attempt will be made to discuss the outlook of psychology on the assumption that, as a branch of natural science, it is primarily concerned with mental occurrences as its sister science is primarily concerned with physical events.

If there be a closed system of physics, and a closed system of mind, each may be discussed in abstraction from the other so long as neither physicist nor psychologist trespasses outside the bounds of his own special province.

But when the day's scientific work is over, they may exchange confidences in the evening. Each wants to know what the other has been doing in his day's work and thought. How far will they get if either says to the other: Those relations which fall under the heading of space and time lie wholly within my province, and do not come within yours? Must they not agree that in some way spatio-temporal relatedness is common to both provinces?

If, however, 'space-time' is in some way common to both provinces, does not that annul the distinction between the two closed systems? On further consideration they may agree that it need not do so. You, says the psychologist, deal with space-time 'as it is,' whether it be apprehended or not. I deal only with 'ideas' of space-time as they take form in some mind. Your 'space-time' is outside my closed system; my 'space-time ideas' are outside your closed system. So, too, your 'physical events' are outside my closed system; my 'ideas' with reference to physical events are outside your closed system.

We are talking of our day's work each in his specialized province of science; let us say 'in single regard.' But now we compare notes in the evening; let us say 'in double regard.' Moreover, even during the day, each holds the other's regard in the background of his thought since neither denies the other's closed system.

It seems then that in double regard we discuss such 'points of contact' as there may be between the two systems, or, in more technical phrase, such 'co-relation' as may obtain between them. One field of joint inquiry in which such co-relation seems to be conspicuously in evidence is that which we speak of as 'sensory perception.'

In this field the physicist deals, let us say, with a ruby; and in this field the psychologist deals with the 'idea' of the ruby. It may then be asked: Does this idea in someone's mind 'represent' something which goes on in the physical ruby?

They may agree that in some sense it does, but may elect not to use this word lest it should be taken to imply 'resemblance.' So they ask leave to substitute the less familiar word 'co-relation,' which is to imply that, so far as it obtains, if one can tell what goes on in this closed system one can infer what goes on in the other. What does go on in either system depends on the relational context, physical or mental, as the case may be.

Thus far physicist and psychologist talk matters over in the evening as colleagues in science. They may, however, be joined by a third party—one who claims to stand for philosophy which, he may say, includes science, but comprises more than science.

I have listened with interest, he may say, to your conversation; but from my point of view there is somewhat lacking. I hear no mention of that which you will perhaps allow me to speak of as Activity. You describe what happens on some occasion, or on all like occasions, and you discuss the 'relations' and 'co-relations' which, as you put it, 'obtain' on such occasions. You say nothing about what causes anything to happen as it does happen. That is what I mean by Activity. You both speak, as I understand, of 'organization'—physical

or mental, as the case may be. But can there be organization in the absence of some directive Activity that organizes? In brief, your aim seems to be to render in generalized terms 'an account of' what happens; but my aim, as philosopher, is '*to account for*' what happens. What say you, Mr. Physicist?

I can only speak for myself, he may reply, for we are not all agreed. I am one of those who, without denying Activity (Force as Cause in the mediæval sense), have no use for it in my closed system. My aim not only 'seems to be' but *is* to render 'an account of' what happens in purely relational terms. It is not for me to 'account for' it. But on this head our friend the psychologist may have something to say.

I agree with my colleague the physicist. I, too, have no use for Activity in my closed system. There are, however, many psychologists who regard creative and directive Activity as the pivotal factor in this branch of science. They urge that its inclusion radically distinguishes the science of psychology from that of physics. Hence it is incumbent on any writer who deals with science to state clearly what he includes therein and what he excludes therefrom. Let me, then, say frankly that in what follows I do *not* include Activity within the closed system of psychology. I regard it as distinctive of the realm which lies Beyond science. Therein I assign to it that which I deem to be its true metaphysical status. Is this unreasonable?

The plain man likes to start from the platform of common sense and quotes with approval the dictum that science is trained and organized common sense. He may, or may not, pause to ask: When in the course of his life-history did he reach this platform? Did he step on to it at birth; did he reach it in his cradle days; or not till in years he was 3½, or 7, or 14? This is a psychological question. It deals with the development of the human mind.

In any case—waiving the question as to how we come by it—we are prone to talk glibly about 'simple common sense'; but when we come to grips with it we find that it is exasperatingly complex.

So we try to simplify it as best we can. And then perhaps

we say that it reduces to this: The plain man has been led to recognize, (i.) a material world of which his body is part; (ii.) minds, his own and those of living beings other than himself; (iii.) Activity or Agency exercised by 'somewhat' or 'someone.' For the plain man these three afford an irreducible minimum. Not one of the three can be dropped out of the reckoning.

No doubt this is over-simplified. It takes no explicit account of time or of place. But for the plain man changes of time and in space are so obvious that they are commonly taken for granted. In due course, however, he is led to realize that just here, in these space-time problems, lies much that is crucial for modern thought.

Let us assume, then, that matter, mind, and activity are three main planks in the common-sense platform. If the plain man join in the talk between physicist and psychologist he insists on *three-fold regard*. And they, too, may (or may not) then agree to include Activity, though each excludes it from his special work-a-day inquiry.

From this three-fold platform the plain man may plunge into the sea of philosophical literature. Let us suppose that he elects to dive into the past some 250 years ago, so that he may compare what was said then with what is being said nowadays.

It may strike him that within five years there appeared three works—Leibniz's *Petit Discourse* (1686), Newton's *Principia* (1687) and Locke's *Essay* (1690). The voices of these three great men he still hears re-echoing today. Professor Wildon Carr's *Cogitans Cogitata* is a Leibnizian monadism brought up to date. Professor Einstein proclaims a transfigured Newtonian physics. In Professor Whitehead's *Process and Reality*, Locke's thought is conspicuously in evidence.

He who bathes in such philosophical waters is no longer the plain man that he was. Not improbably, however, he cherishes a core of common sense. He is still, therefore, likely to ask: What about matter, mind, and activity? He may say: In monadism matter, in independence of mind, seems

to have been served with notice to quit. There remains only the Activity of monadic 'minds.' In modern physics matter, under some new guise, say, wave-mechanics, seems to occupy the whole field. Mind save as occasional onlooker has been given notice to quit. So, too, has Activity.

Thus far, in the strictly closed system of psychology as a science of mind—and that is what we want to get at—we may say: Exit physics. It is relegated *in science* to a closed system which this or that human mind contemplates. And, thus far, monadism is a closed system of purely mental relations with emphasis on Activity to account for all that happens.

What then of Locke? In his capacity as psychologist he championed a 'doctrine of ideas.' And for him all ideas, whether they 'come from' sensation or reflection, are purely mental.

But, in double regard, the ideas which come from sensation indicate the presence of 'sensible objects' which have 'qualities' such as shape, hardness, and colour.

Locke and his reader then get into difficulties since 'ideas' and 'qualities' are often so spoken of that it is hard to say which is meant. Let us therefore leave seventeenth-century Locke and exchange notions with his twentieth-century reader. Then, keeping to Locke's terms, this thesis may be submitted for consideration. Sensible objects, as such, and all their qualities, lie wholly within the closed system of physics; all ideas, as such, lie wholly within the closed system of psychology; Activity, as such, lies wholly Beyond either system.

According to this thesis we all start, as plain folk, with some such common-sense notions as matter, mind, and activity. Locke unquestionably did so. He was only feeling his way towards a clear distinction between sensible objects within an abstract system of physics, and ideas within an abstract system of psychology. He retained the common-sense notion of activity or power. Berkeley held fast to ideas, but denied that they indicate anything material or physical. For him the sensible object just *is* a cluster of ideas. He held fast also

to spiritual Activity. Hume, though he drew a subsidiary distinction, purely psychological, between 'impressions' and 'ideas,' sought always (in the study) to keep within a closed system of mind. And in his polemic against causality he resolutely banned all reference to Activity.

Along this historical line of advance, carried farther, we reach a closed system of psychology as distinguished from a closed system of physics. Activity lies Beyond the purview of either closed system.

Let me use the word 'Beyond' for that which may be reached by transgressing the 'methodological' boundary between science and philosophy; and the word 'outside' for that which is reached in passing from this to that province of science—say, from psychology to physics. Locke passed freely to and fro across the latter frontier. And few men of science today refrain from doing so when they prosecute inquiry within *both* provinces of science in their double capacity. In this sense they may say that what as psychologists they deal with as ideas 'in mind' are for them as physicists certain co-related qualities in sensible objects or external things.

The question then arises: Can we say that any idea in mind 'resembles' a quality in the sensible object? Locke, in effect, replies: Yes; at any rate in some cases. His belief (in line with that of sundry predecessors, Galileo, Boyle, and others) was that some ideas do resemble, whereas other ideas do not resemble, though they 'correspond to,' the 'real' qualities of sensible objects. It seems then that only through these resemblant ideas do we learn the nature of sensible objects as they are 'in themselves.'

Locke's successors have again and again discussed the validity of this distinction between 'primary' and 'secondary' qualities. Berkeley long ago denied its psychological validity. Professor Whitehead today, on the basis of direct apprehension, denies its physical validity. It may perhaps be said that both parties meet on common ground in so far as the one brooks no 'physical additions,' the other no 'psychic additions,' to his closed system.

But on these terms there seems to arise a serious deadlock. For the plain man is convinced that there is some connection between the qualities of things and the ideas which indicate their presence in these things.

It remains, then, for the physicist and the psychologist in joint session—when they regard each closed system as in some way complementary to the other—to suggest an avenue of escape from this dilemma. The outcome may be that the co-relation between the two systems is such that, given all that is in mind, the physicist could infer what relevant physical events are in progress—including of course those in body and brain; and that given these physical events the psychologist could infer all that is then in mind.

In a closed system of physics, inquiry is restricted to physical relatedness (relations and relata) within a frame of physical space-time. Similarly in a closed system of psychology inquiry is restricted to mental relatedness within a frame of space-time ideas. But in joint session men of science discuss the evidence for co-relation.

Let us now accompany the psychologist in his day's work on the assumption that, in 'singular' regard he prosecutes his task within a closed system of mental relatedness. He has, let us say, a ruby before him. What is it for him as psychologist? A pretty complex idea to which there is on his part mental reference set in a context of other such relevant ideas. And what is he? When he reflectingly thinks of himself 'he' is the very complex idea to which, in thus thinking, there is mental reference on his part.

One is dealing with one's own reflective experience, and taking such interplay of ideas as one finds; and what one commonly finds is subtly varying reference to the idea of oneself as having in mind reference to ideas of surrounding things and events.

Thus stated this may sound rather awkward. But it is among the commonest and most familiar of occurrences. For example, one has an idea of oneself seeing the ruby yesterday or tomorrow. That, however, introduces retrospective reference to oneself and the idea of the ruby in the past; or

prospective reference to oneself and the ruby-idea in the future. It introduces the idea of 'time' and if one 'pictures' oneself as seeing the ruby on the ring-stand this morning and on one's wife's finger this evening that introduces the idea of place.

We have, then, the ruby-idea, the self-idea, the time-idea, the space-idea, and many others. Thus the word 'idea' in this its most comprehensive sense means 'somewhat to which there is mental reference.' And outside, or Beyond, that somewhat 'in mind' the psychologist, if he keeps within his closed system, does not pass. When he reverts to common sense, however, he always so far keeps 'double' treatment in view as not to preclude reference to the co-related body and its physical surroundings. For the presupposition here is that he is also a physicist in some measure, and that, as physicist, he fully accepts that closed system also.

None the less, in the foreground of his thought the psychologist keeps steadily in view occurrences within his closed system of mind.

Within that system there are those factors in experience which, following Locke, we have called ideas—such as the ruby-idea and the self-idea. But there are other factors in experience. One is aware in seeing the ruby. One is aware in thinking of oneself. One is aware, too, in thinking of yesterday's self as having been then aware in seeing the ruby.

The word 'awareness' is here used, qualified by 'in' ('awareness in') to name some mode of experiencing. One such mode of experiencing is that of behaving. This, in double regard, is co-related with some bodily process in singular physical regard, which, as such, is outside the closed system of mind. Awareness in behaving and all other modes of awareness, are purely mental and primarily individual; as indeed is all experiencing.

But if I see you, or an infant behaving, there is on my part no awareness in behaving on your part or his. It is you, or he, that may be thus aware. Still I confidently believe that you are, and he is, aware in so behaving. So, too, I con-

fidently believe that you are, and he is, aware in seeing or in touching, or more generally in any such mode of experiencing.

We here take over a common-sense belief which carries 'pragmatic' endorsement on the platform of each plain man's daily life. And though one may be assured on good authority that it is not susceptible of strict logical proof, still if one were stoutly to decline to do so psychology, as a science, would be in sorry case. For then each of us would be confined within the closed system of his own first-hand experience (solipsism).

Let us accept this current belief. Then, to label what happens let us say: Each of us 'imputes' to others, human folk and many animals, first-hand experience, in some measure like his own. And this is to apply, not only to awareness in behaving or in seeing but to the occurrence of ideas in any mind other than one's own. For if I may not impute to an infant awareness in seeing, on what grounds may I impute to him reference to anything seen, or indeed ideas of any sort? Such 'imputation' (as it is here called) is quite distinctively psychological. It has no place in a closed system of physics. But it extends the closed system of psychology to experience in other minds than one's own.

It is questionable whether the word 'experience' can be satisfactorily 'defined.' Let us regard it as distinctively mental; and for the rest let us be content to say to one's neighbour: You have long ago learnt what it is far better than anyone else can tell you. We may, however, now distinguish (1) factors of awareness in 'feeling,' and (2) factors of reference to an 'objective field' of ideas.

To the objective field of ideas under reference we may now turn; and since our aim is to get down to fundamentals it will be well to start with what seems to be common to any mind at any stage of its development. We may start, then, with sensory experience. That may seem simple enough. It brings us down to such basal ideas as are ours by way of touch, taste, smell, hearing, sight. But under our sensory ex-

perience some would include seeing the thing *there,* and having seen it *then.* Thus space-ideas, and time-ideas, are introduced. Let us, however, proceed analytically, and *distinguish* space-ideas and time-ideas, respectively, from sense-ideas.

In 'perception,' as this word is here used, these sense-ideas combine with space-ideas and with time-ideas. They enter into 'associative organization' and thus give new wholes which, as many believe, are, in their characterizing features, 'more than' that which is given in the algebraical summation of their partial constituents.

Speaking, for example, at the beginning of this century, of James Mill, Professor Höffding says that, he "lays great weight on the point that . . . several ideas and feelings may enter into so intimate a union with each other as to become inseparable, while the new totality, thus formed, possesses qualities which are not possessed by any of the parts." "The new qualities of the product cannot be deduced from the factors." This feature of progressive organization—whether it be spoken of as 'heteropathic,' 'emergent,' 'holistic,' 'organic,' or be called by some other name—is emphasized by many thinkers today. It will be accepted here.

Locke distinguishes those ideas which 'come by sensation' from those ideas which 'come by reflection.' This implies that there are (at least) *two* levels of mind, unreflective and reflective.

Let us concentrate attention on the human mind as reflective and return, later on, to the unreflective processes at subordinate levels. It is in the reflective processes of daily life that we find ideas of self, and a plan or frame of space-time ideas in which patterns of sense-ideas are set. It is here that we find ideas of past or future occasions; with retrospective reference to an idea of self on some past occasion (reflective memory); and with prospective reference to an idea of self on some future occasion (reflective anticipation).

Is that all? No; far from it. The inter-relations between retrospective and prospective reference are very complex. Let us take some ordinary situation and psychologically dis-

entangle some of the threads of its intricately interwoven meshwork.

I received, let us say, an hour ago a telephone message from a friend that he will call for me in his car for a run in the country. I now picture myself then in the past, receiving the message with a: "Good; we'll take Bodiam Castle in our round. I want to see the water lilies in the moat." A moment later, with change of attitude, I picture myself then, in the future, seeing the water lilies with a: "Splendid. I thought so;" or a: "What a pity; not yet in full bloom." Even that is not all. When I picture myself then, in the past, 'he' (my pictured self) is picturing himself then, in the future, at the moat-side. And when I picture myself then, in the future, looking over the water, 'he' then looks back on what in anticipation he hoped to see, with an: "Even better than"; or a: "Not so good as." If the former there will be satisfaction; if the latter disappointment.

We thus introduce 'affective tone,' pleasurable or the reverse, of which this only need here be said, that it qualifies the total *awareness*—sentient, perceptive, and reflective—in the current experience of the time being. This statement should be checked in the light of each person's first-hand experience.

Let us now suppose that the incident is over as an affair of yesterday. One reviews it in retrospection, or let us here say, in 'reminiscence.' It clearly presupposes a space-time plan with self in the thought-picture. But within this schematic frame of mental occurrences we can distinguish and emphasize *two* occasions, an earlier, on receipt of the message, and a later, at the moat-side. On the earlier occasion what is relevant in mind is anticipation with prospective reference to the later occasion. On the later, what is relevant is retrospection with reference to the earlier. In reminiscence, then, one has *both* occasions under review, but each in relation to the other. One pictures oneself on the earlier occasion, as 'wishing' to see the lilies; and as satisfied or disappointed on the later occasion. The wish, however, in picturesque phrase, has, under anticipation, subsequent satisfaction in

view; it is a wish to be satisfied. The satisfaction has, in retrospection, the precedent wish in view. It is the satisfaction of that wish.

One may say, then, that, *at the level of reflection*, there is no wish without some 'end in view' to be fulfilled, if all goes well, on a later occasion; and no satisfaction on this later occasion in the absence of some relevant wish on an earlier occasion.

Let us here pause to ask: What exactly, in this reflective context, are we to understand by the word 'wish.' It here implies an end in view. This end in view is in the objective field of reference. But 'one wishes' to attain it and thus to reap satisfaction. No doubt, that which one wishes to attain (sometimes spoken of as 'the objective'), may itself be called 'a wish.' We may, however, elect so to define it as to lay chief stress on the mental attitude of *awareness in wishing*. The emphasis then falls on this mode of experiencing on someone's part. It must be felt in first-hand experience that one may say what it feels like.

One may fairly assume that we all do know quite well what it feels like as specific and *sui generis* in the mental life of reflection. With emphasis, then, on its distinctive character as a familiar mode of awareness we have a relation between someone wishing on an earlier occasion, and an end in view as the objective to be attained in some later occasion.

This, for the psychologist, is a 'teleological' relation.

There can be no doubt that teleological relations obtain at the reflective level of mentality. But do they obtain also at levels below that of reflection? Is there *always*, on any 'this' occasion, anticipation with prospective reference to an occurrence on some future occasion. Here psychologists of different schools frankly disagree. An extremist of one school may say: Yes, always. All mental relations are *au fond* teleological.

Other psychologists have been led to a different opinion. They say: Not always. They say that on those occasions on which they are themselves unreflective they find in their own first-hand experience no sufficient evidence of teleologi-

cal relations with prospective reference to some *future* occasion. They find only *one* occasion, that of the now of the 'specious present.' But, within the one occasion they find that which I ask leave to speak of as 'fore-experience.' It may, however, be said that so-called fore-experience itself supplies, nay is, the end in view. Is that so, however, if an end in view has reference to some occurrence on a *subsequent* or later occasion? My finding is that unreflectively one does not think of a subsequent occasion. One is immersed in the current occasion. As I lift a glass of water to my lips I detect *now*, on *this* occasion, fore-experience of drinking before I actually do so, though reflectively I may also have the end in view of quenching my thirst as the result of drinking. The discussion seems thus to turn on the presence or absence of teleological relations in unreflective procedure—a purely psychological question. And there we must leave the matter *sub judice*.

One may, however, still ask: On whose part is there that anticipation, with prospective reference to some future occasion, which is essential to the very being of an end in view to be discussed under teleology? The reply may be: On the part of some individual mind as a unitary whole and not less than a unitary whole. Under imputation it is your mind, or that of Chica the chimpanzee, of Cæsar the dog; of some cow, rabbit, frog, fish, lobster, earthworm, amœba; in each case this or that mind one and indivisible.

This is widely accepted. By the method of analysis, however, the psychologist distinguishes a great number of wishes. He then proceeds to classify these wishes (this one word is here selected—others such as 'impulses,' 'instincts,' 'urges,' may be substituted at discretion); and he does so in accordance with their 'outcome' in experience, imputed on the basis of behaviour. This inquirer may work with 6 classes; that inquirer with 12; others with less than 6, or more than 12. Of each well-devised scheme one asks: Does it work?

One cannot enter into details. What calls for emphasis here is that each several wish may thus be regarded as (or 'as if' it were) a 'monadic mindlet,' so that one may say:

This or that monadic wish has this or that end in view, and plays its part in alliance with others that have a like end, or in conflict with others whose ends are different.

The question then arises: If any given mind is a unitary whole, do not all the monadic wishes, as constituent factors, play their parts in subservience to, and never 'apart from,' that whole? Thereon the further question arises: May not this be subject to the 'organic' or 'emergent' principle? May not wishes "enter into so intimate a union with each other as to become inseparable, while the new totality thus formed" (ultimately the mind as a whole) "possesses qualities which are not possessed by" the wishes taken severally as parts?

But question leads on to question; and this in due course follows: If the treatment is thus far monadic; and if in monadism the hinge-concept is Activity; has one not already passed beyond the closed system of psychology which, as such, is objectively restricted to 'ideas' in the mind? In much current 'doctrine of wish,' Activity is either overtly expressed or covertly taken for granted.

Only under rigidly abstract treatment is there a closed system of physical events or a closed system of mental occurrences. On these abstract terms, however, there is neither give nor take between one closed system and the other. There are no 'psychic additions' to the one; no 'physical additions' to the other. Nor is there 'interaction' of one on the other. If there were interaction one or other system would no longer be closed.

None the less there is, on this hypothesis, so intimate a co-relation between some physical events in the body and some mental occurrences that with regard to them either physicist or psychologist may say: If you tell me what goes on in your closed system, I can infer what, relevant thereto, goes on in mine, although physical relations and mental relations are quite different in kind and nowise interact.

On the assumption, however, that there is no interaction, this co-relation must be accepted as we find it. All one can say is: Such is the constitution of nature. To account for it

one must go beyond either closed system and invoke some Activity to which the 'harmonious' organization in both systems may be due.

That is what the plain man habitually does on the basis of common sense. He says: Your denial of interaction is merely a theoretical consequence of your abstract treatment under two closed systems, and of your refusal to entertain the concept of activity to account for the co-related organization in both systems. Against this he raises his voice in protest. You men of science, he may say, seem 'out' to deny activity in any form. Here, if you will allow me frankly to say so, you are hopelessly 'out of date.' Modern psychology has now reinstated activity; and one may see good signs of its reinstatement in modern physics also.

To this the psychologist may reply: If you will allow me to be equally frank, you are here 'off the rails.' Those for whom I speak do *not* deny Activity. They say that psychology as a branch of science seeks only *to render an account of* the progressive organization of mind in terms of such mental relations as we find within our own first-hand experience or may be led on the evidence to impute to others. It is not concerned with such Activity as may be—perhaps must be—invoked *to account for* this and all other modes of organization. That lies beyond the strictly limited scope of scientific inquiry.

Where we differ is that you include this Beyond under 'science' whereas I exclude it. You may ask on what grounds I exclude it. In brief, on historical grounds. During the seventeenth, eighteenth, and nineteenth centuries the word 'science' gradually acquired a well-recognized meaning. The man of science professed to render a 'natural' account—in due course an 'evolutionary' account—of all that happens. That and no more than that was his aim. There were, however, other folk than science folk. There were poets, historians, artists, philosophers, and upholders of religion. They sang, taught, and preached creative Activity that lies Beyond the purview of science.

Here were rival claims on the plain man's allegiance. And

the plain man assigned these claims to science on the one hand; to art, morality, and religion on the other hand. Since religion often lay nearest to his heart, he put that in the forefront, and emphasized an antithesis between science, with its natural worldliness, and religion with its spiritual otherworldliness; between the world of science and a realm Beyond science. Hence he was faced by the question: Which is it to be, religion or science? He may have decided for one or the other; perhaps for one on Sundays, the other on weekdays. Or he may have said to himself: Why not both all the year round? But if both, on what understanding? Perhaps he sought counsel from others?

On the one hand he might be advised to include Activity in science; in other words to annul the distinction which for so long was regarded as that which earmarked science, as such. He finds, however, that many men of science do exclude Activity as beyond their province of inquiry. For them such words as 'Force' (in the mediæval sense), 'Élan vital,' 'Entelechy,' have no place in the scientific vocabulary. He finds, too, that many poets, historians, artists, and moralists —and most upholders of religion—*do* include much that they regard as Beyond science. And he may believe that the distinction which both parties draw is a valid and helpful distinction. So he asks: Is there no other way out of the difficulty? and seeks further advice.

Then some may bid him regard all science as deliberately and professedly abstract in its aim. Each science selects certain relational factors and concentrates inquiry on them. The aim of each—say in physics and in psychology respectively—is a limited and circumscribed aim so long as each keeps to that kind of relations which he has chosen as his specialized field of intensive culture. And what is that aim alike in the case of the physicist and of the psychologist? First, in singular regard, to render an account of all that happens within this or that closed system, as such, in terms of broad generalizations in large measure statistical in their nature. Secondly, in double regard, so to compare results as to consider, in joint session, how far the conclusions which

are reached by the physicist in his closed system can be 'squared' or 'co-related' with those which are reached by the psychologist in his closed system.

On these terms, if the squaring be such that each party can say: Given *this* in your closed system I can infer *that* in mine; neither goes beyond science, though each goes outside his special province of scientific inquiry.

Each may then say: It seems that between us we cover the whole field that lies open to serious inquiry. What call is there for either of us, or anyone else, to go Beyond science?

The question then arises: What, if anything, does lie beyond science?

One traditional reply is: That which lies beyond science is the whole realm of art.

It may then be said that interesting chapters in general literature deal with the historical development of artistic ideas and their varied expression in creative art-production. They are chapters which elucidate certain upper reaches of human endeavour where very highly elaborated aims are 'in mind.' But they are concerned also with delicate nuances of perception, with differentiated space-time ideas, and with the deeper-lying sensory endowment which lies near the foundations of mind! Above all, the emphasis falls on peculiar and specialized modes of appreciative awareness which are felt by the artist within his first-hand experience.

All this affords data for consideration within the province of psychology. It may be asked, for example, whether the peculiar mental attitudes of appreciation in the mind of the artist are in being only at the reflective level of mental development. A difficult question for introspection and imputation is thus opened up. And though one may so analyze the mental situation as to disclose many factors, it still remains possible, perhaps probable, that in combining to form new wholes they do not of themselves tell the whole secret, since, as wholes, these attitudes may have nuances which could not be deduced from those of the factors taken severally.

Many psychological questions in connection with the mental procedure of the artist arise. But in so far as the

treatment is psychological, stress must still be laid on the development of artistic ideas, aims, attitudes, behaviour-awareness in execution, joy in attainment. Beyond his closed system of feelings and ideas the psychologist as such does not pass.

Is this good enough? The artist proclaims that it is *not* good enough. What the psychologist with all his probings and searchings fails to discover is that creative Activity, operative in him or through him, of which the art-product is the visible or audible expression. The art-product itself lies open to inspection; the process of art-production may be observed; the feelings and ideas in passage through the mind may be imputed by one who is himself in some measure an artist. But the creative *élan* of the artist as agent escapes the net of scientific generalizations. This lies beyond science; and it is in terms of this that one must seek to account for—not merely to render an account of—what happens.

Akin to art, but with felt difference of attitude in approbation, is morality. Here, too, the conduct of men lies open to inspection. Its genetic affiliation to the behaviour of animals may be traced by careful observation of overt acts. The psychologist deals with current sense-ideas; with objectives, unreflective or reflective; with the aims to be attained through action; with joy in their attainment; with awareness in behaving during action; with the mental attitudes which have that peculiar 'flavour' we name 'moral.' The historical development of moral ideas with liberal diffusion of correlative feeling may be set forth at large. Abundant data for consideration within the province of psychology are provided.

And yet this does not touch that which raises the man to the status of an agent. Here is directive Activity which lies beyond science. And here—though not only here—there is emphasized that insistent claim for freedom which shall express the individual uniqueness of the agent in contrast with the merely statistical net results with which science so largely deals.

The keynote of that which lies beyond science in art or

in morality is Activity on the part of some human Agent. The keynote of that which lies beyond science in religion is Activity on the part of some agent who is regarded as Divine. Here, too, all religious ideas, the sublime ends in view to be attained, the distinctively religious attitude with its 'sweet savour of sanctity,' the joy in participating in Activity regarded as more than human; all this falls for consideration by the psychologist even if it be only, in his opinion, a tissue of dramatized fiction.

The psychologist as man of science claims that in art, in morality, in religion, there has been, alike in the race and in each individual, advancing development of ideas and correlative nuances of feeling. He seeks to tell its story in terms, let us say, of evolutionary organization. If he keeps within his restricted province of inquiry it is not for him to account for this progressive organization of which he renders a generalized account. That lies Beyond science.

In brief, the man of science, as such, is concerned only with the evolutionary advance of organization. The philosopher is chiefly concerned with the creative Activity of which this is the expression. If the man of science claims that the evolutionary process is universal, the philosopher urges that no less universal is creative and directive Activity. Neither is antithetical to the other. Each is complementary to the other. If the goal of science is to render an account of such organization, physical and mental, as is disclosed under diligent inquiry, it still remains open to the philosopher to postulate an organizing Activity, one and indivisible, universal and in some sense eternal. This it is that lies Beyond science.

When the physicist has said his last word on the organization of events within his closed system; when the psychologist has said his last word on the organization of mental occurrences; when in council together they have said their last word on such co-relations as may obtain between mental occurrences and highly specialized events in the living body; the philosopher wants something more. We are told, he says, much of what happens; we are told much of the relational

'how' of what happens. But we are told nothing of the creative and directive Activity in terms of which we would fain account for all this. If such there be it lies Beyond science.

If there be some universally directive Activity that organizes all physical events and all mental occurrences in such close inter-relation as led to the old-world notion of 'pre-established harmony,' the question does not arise whether there is 'interaction,' 'interference,' or 'control,' one-sided or reciprocal, between physical events and mental occurrences. For if all physical events and all mental occurrences are, on all the occasions of their co-relation, the 'expression' or 'manifestation' of universal Activity, the concept of interference or interaction is superseded when we pass Beyond science.

But if the Activity that organizes lies beyond science, say, as a philosophical 'postulate,' can the psychologist, as such, tell us anything about it? Clearly not, so long as he keeps within his closed system of ideas.

It is no doubt very difficult to decide whether introspection does, or does not, disclose directive activity within first-hand experience. Some find it and some do not. Let us assume that not only the idea of activity—which of course everyone finds—but that which this idea 'symbolizes' may be found at the reflective level of mental development as part of and one with the ego of mediæval thought; still this falls far short of that directive activity which is conceived as the organizing source of all that the man of science is content to accept as exemplifying a bewildering number of modes of relational organization. There is still a wide range of the philosophical realm which lies beyond the reach of introspection.

Into this realm, even in philosophical regard, still less in more intimate religious regard, one cannot here enter. The point for emphasis here is that this realm lies Beyond any closed system of science, but not beyond reality.

If then the psychologist in his vocation as man of science has occasion again and again to come into contact with those

who account for art, history, morality, and religion in terms of the directive Activity of human agents, or those who ultimately account for all evolution in terms of the directive Activity of an Agent whom they speak of as divine, he raises no protest—nay, he may be ready to accept and endorse their belief; but *not* as man of science. As man of science he says: Let us keep to such relational treatment as falls within our closed system of psychology.

Alike in a closed system of physical events and in a closed system of mind, the time-problem is crucial. What form does it assume if we pass beyond science?

It is commonly held that the Beyond is in some sense eternal. This is sometimes taken to imply unlimited duration, without beginning and without end—or at any rate endless.

If, however, by 'eternal' we mean 'timeless,' it is clear that no time-problem can arise in reference to the Beyond as in *this* sense eternal. But under the heading of 'teleology' a difficult question and divergent answers are introduced into the field of discussion.

We have seen that for the psychologist teleological relations are distinctively mental. At the reflective level of human development they imply a precedent end in view. At the perceptive level the mental relations which are their predecessors imply at least fore-experience that forestalls some coming event. We thus deal with process in time. There is incipient or more fully developed reference to the future.

Is then universal Activity to be regarded as a process in time? One here means Activity itself, not the instances or occasions of its operation which are, no doubt, spread out in temporal and genetic array.

Those who have been led to believe that all that happens is the expression of universal Activity, creative and directive, one indivisible and timeless, are clearly precluded from regarding it as itself a process in time. If then they still use the word 'teleological' it must be in some different sense. In this sense it implies neither prospective reference to the

future nor retrospective reference to the past. What then does it imply?

May one say, timeless purpose of which all that happens in time is the fluent expression? If so, the word 'purpose' needs suitable definition as timeless. And if we speak of this purpose as 'teleological,' this word needs suitable re-definition so framed as not to imply aught that is 'infected by time,' such as a precedent end in view or subsequent satisfaction in its attainment.

Science tries to get down to fundamental principles in terms of which an account may some day be rendered of all that happens, has happened, and will happen, including all that those who are 'immersed in time' label new and unprecedented. Such is the goal of scientific endeavour, obviously unattainable so long as the temporal universe is still in the making.

But natural science knows nothing of timeless purpose. If, then, the philosopher seeks to pass Beyond science in an endeavour to account for, and not merely to render an account of, all that happens, he should preserve the distinction between the things temporal of science and Divine Purpose as Beyond time and eternal.

SOCIOLOGY AS A SCIENCE

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SOCIOLOGY is the youngest of the sciences, and there are still many who question its right to be considered as a science at all. It is but a century since Auguste Comte announced the advent of the new science that was to be the keystone of the scientific edifice and the crown of man's intellectual achievement, and though the last hundred years have seen a great increase of interest in social questions and an enormous production of sociological and semi-sociological literature, there is still little prospect of the realization of his ideal. In fact, there has been, in some respects, a distinct retrogression from the position that had been reached in the middle of the last century. Sociology no longer possesses a clearly defined programme and method; it has become a vague term which covers a variety of separate subjects. Sociologists have abandoned the attempt to create a pure science of society and have directed themselves to the study of practical social problems.

Sociology seems in danger of becoming a scrap-heap on which are thrown any items that cannot otherwise be disposed. Nor is this the only danger. Even the writers who do deal with genuinely sociological problems frequently do so in an entirely unscientific way.

This is most unsatisfactory, not only from the point of view of the sociologist, but in relation to the scientific outlook in general. The problem of sociology is probably the most vital scientific issue of our time, for if we admit the impossibility of creating a scientific sociology we are confessing the failure of science to comprehend society and human culture. It is impossible to create a scientific civilization from outside by

a development of the material resources and the external mechanism of society. There can be no scientific civilization without a science of society. You cannot plan the future of a society if you have no knowledge of the true nature of the society in question. Moreover, at the present day the plans of the economists are at the mercy of the policies of the politicians, and the politicians themselves are the instruments of a public opinion which is swayed by obscure and non-rational forces. The statesman who fails to understand these forces is a failure, but his failure is often less dangerous to society than the success of the "practical politician," who understands how to use these forces for his personal advancement without understanding their social significance.

The crisis of so-called scientific modern civilization is due to its combination of an elaborate technical and mechanical equipment with an almost complete lack of social direction. The societies of the past possessed their own organs of social direction and their formal principles of order, which were not indeed scientific, but were based on social tradition. Modern society has abandoned this social traditionalism in the name of rational principles, but it has done little to create the foundation of scientific sociology that these principles seem to demand. Instead of this our social order is still based on the political and moral dogmas of the philosophers of the eighteenth century. The doctrines of modern democracy are not a scientific theory, but a moral and semi-religious creed which owes more than we generally realize to the personal inspiration of Rousseau and is hardly separable from the mystical Deism with which it was originally associated. This doctrine is, in reality, much further from scientific sociology than was the old Aristotelian political philosophy, which was, within its limits, firmly grounded on a basis of observed facts and a rational theory of social life and development. Moreover, the new movements that have arisen in opposition to the dominant theories of liberal democracy are also deficient in a pure sociological foundation, and are derived either from the economic theories of the nineteenth century or from the political philosophy of nationalism.

Thus we are faced by the contrast of a highly specialized development of scientific technique in the external conduct of life with an almost complete absence of scientific direction in regard to the life of society itself. And yet there can be no question of the vast resources of social knowledge that have been accumulated during the last century and more. The modern development of history and anthropology, of economics and of the comparative study of religion is hardly less remarkable than that of the physical sciences. A new world has been opened up to us in the past, and our resources for the understanding of human development and its social processes have been immeasurably increased. There is no a priori reason for excluding all this new knowledge from the field of science. It is genuine scientific knowledge as reliable and as systematic in its own sphere as that of the physical sciences. It is no mere collection of scattered facts and subjective opinions, but an organized department of knowledge, or rather a number of such departments.

Why, then, need we despair of the science of society when the available resources of knowledge are so great and the need is so obvious? But the fact is that these conditions, that are at first sight so favourable, have actually been a hindrance rather than a help to the development of sociology. The most successful sciences are those, like physics and mechanics, which found their method before they were involved in a mass of detailed observation and before there was any question of using them for practical or utilitarian purposes.

The development of Sociology has followed the opposite course and has suffered accordingly. It started with an embarrassing wealth of material and a desire for premature practical results, but with no assured method. The besetting sin of the sociologist has been the attempt to play the part of a social reformer, whether, like Comte, he embarked on grandiose schemes for the reconstitution of society or, with the modern sociologist, he plunges into the practical work of civic reform.

The early sociologists were great systematizers with a gift for generalization that carried them far beyond the limits of

sociology proper into the deep waters of ethics and metaphysics. They improvized a whole philosophy as a basis to their real work as sociologists, with the result that they came to think more of their philosophy than of sociology itself. Thus the efforts of the Encyclopædists, the St. Simonians and the Positivists resulted in the creation of a theory of society which was at the same time a philosophy of history, a system of moral philosophy and a non-theological substitute for religion.

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This identification of Sociology with philosophy tended to bring the whole subject into discredit and caused a considerable body of opinion in the later nineteenth century to despair of the scientific possibilities of sociology, and to look instead to the new science of anthropology as an alternative. It caused sociologists themselves to react against the speculative tendencies of the earlier sociology, which they condemned as "armchair sociology," and to immerse themselves in detailed statistical and practical enquiries which alone seemed to offer a prospect of concrete results. But the new movement avoided rather than solved the real problem of scientific method, and it often involved a substitution of the study of social machinery for that of society itself. Nor did it even escape the old danger of abstract philosophical generalization. Modern English and American sociology remains to a great extent dependent on the old tradition of eighteenth-century moral philosophy. In America, especially, the ideal of the ethical reconstruction of society tended for a long time to dominate sociological thought, and one of the leading American sociologists of the last generation even went so far on one occasion as to define sociology as "a moral philosophy conscious of its task." It is easy to understand how, under the existing circumstances, the sociologist was forced to look to an ethical ideal for guidance and help. But nothing could in fact be further from the ideal of scientific sociology and it led merely to the creation of a pragmatic system of social ethics that embodied all the impurities and

confusions of thought that it is the purpose both of philosophy and science to eliminate.

The continental schools of sociology, on the other hand, have been far more conscious of the need for a strict definition of scientific method and for the delimitation of the province of sociology from both that of philosophy and that of the other social sciences. Hitherto, however, they have not been altogether successful, although they have accomplished much valuable work. Their efforts have been handicapped by the confusion that has characterized the development alike of modern philosophy and that of the social sciences. In the case of the latter there has been an overlapping, due in part to the riches of the available material, in part to uncertainty of method, and also in part to a non-scientific rivalry between the different sciences.

This has been most serious in the case of the two new sciences of Sociology and Anthropology, which have been, from the beginning, competitors in the same field. They started out, like rival prospectors, to establish as large a claim as possible in the unoccupied territories of the new world of knowledge; and consequently they both occupied far more territory than they had the means to develop. Both of them take as their motto "Nihil humani alienum esse puto." The Sociologist claims all social phenomena as his province, and there are few human phenomena that are not social. The Anthropologist claims that his science is the science of Man and of human development, and consequently includes everything from human palæontology to the comparative study of religions.

It is obvious that if these claims are taken at their face value, neither science leaves any room for the other, except in so far as the sociologist does admit the existence of physical anthropology as an independent discipline. We may almost say that both sciences deal with the same subject, and that they differ only in the manner of their approach. In practice, however, a certain *modus vivendi* has been reached, although it is neither logical nor final. The Anthropologist deals with primitive man and his society and culture, the Sociologist

with the more advanced cultures and with the phenomena of contemporary social life. The Anthropologist has had somewhat the better of the bargain, since his material lends itself more easily to objective scientific study, and consequently he has done as much in recent years for sociological studies as the sociologist himself. This is particularly the case in America, where anthropologists, such as Kroeber, Wissler, Lowie and Goldenwieser, have produced works which are admirable introductions to sociological study and are far superior in scientific method to the average textbook of Sociology.

This superiority is largely due to the fact that, in dealing with primitive cultures, the anthropologist is not embarrassed by the rival claims of the historian and the archæologist. The archæologist and the anthropologist co-operate with one another in the study of primitive culture, and there is no attempt on the part of the one to dispense with the help of the other. The case of the sociologist is very different, though through no fault of his own. It was hardly to be expected that the historian should welcome the co-operation of the sociologist, in the same way as the archæologist and the pre-historian have welcomed that of the anthropologist.

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The advent of Sociology found history already in possession of an established position and enjoying a well-earned prestige. It was regarded, not as a science, but as literature; it was a branch of the humanities, and as such must be judged by artistic rather than scientific standards. This conception goes back in origin to the historiography of the ancient world from which our own historical tradition is ultimately derived. To the Greeks history was a form of rhetoric and had nothing in common with science, which finds its true pattern in mathematics and geometry. Science is concerned with the universal; history with the particular. Science belongs to the world of absolute and eternal reality; history to the world of time and change. Science is Truth; history is Opinion. In this respect every Greek was a Platonist at heart and shared Plato's belief

that the less a science has to do with *facts* which are inevitably subject to perturbation and change, the more perfect it is, and the more it immerses itself in the sensible world, the less right has it to be considered scientific. Now this ideal, stripped of its metaphysical connotations, has been passed down by the scholars and scientists of the Renaissance to modern times, and has had a profound influence on current conceptions of history. Right down to our own days scholars have continued to repeat that history is not science, because there can be no science of the particular, and history is concerned with the study of particular events.

Consequently the historian is driven either to fall back on the old literary-rhetorical ideal, which still possesses a distinguished champion in Professor Trevelyan at Cambridge,[1] or to return to the ethical ideal and like Acton to attribute to history the office of a moral censor, or, finally, with Croce to identify history with philosophical intuition.[2]

But none of these alternatives is really satisfactory to the modern historian, and the prevailing tendency is to maintain the independence of history at all costs by treating history as an end in itself.

The most distinguished representative of this tendency was the late Eduard Meyer.[3] His attitude to history was, indeed, that of the scientist rather than the man of letters, and has nothing in common with the literary-rhetorical ideal. But on the other hand he maintains the absolute dissimilarity of history from the other social sciences, and bases its claim to independence precisely on the old argument of its particular and individual character. Sociology and anthropology seek, no less than the sciences of nature, to submit human development to general laws and to order the multiplicity of social facts according to universal concepts. But in history there is no room for general laws or causal principles; its world is the world of chance and free human actions, and it cannot pass

[1] *Clio, a Muse.*

[2] *Theory and History of Historiography,* Eng. trans. 1921.

[3] See the Introduction to the third edition of his *History of Antiquity* (1910), especially ch. iii.

beyond this. That is why, he says, "the modern attempts to transform the essence of history, and to set before it other and 'higher' tasks, leave the historian unmoved: history exists once for all, such as it is, and will always maintain itself in this form, and the business of the historian is with things as they are and not with abstract theories. Whether history is valued more or less is a matter of no concern to him."

But in reality, as J. B. Bury has pointed out, it is impossible to dismiss the question of the significance of history as a matter of no importance. If history has no end except the collection of facts for their own sake, it becomes merely an intellectual pastime, like stamp collecting. If it is to receive the respect that it has always claimed, it must mean something in terms of reason and have some relation to the social sciences. The fact is that this opposition of history and science ignores the whole change that has passed over the world of knowledge since modern science and modern history made their appearance. Modern science does not aim, like that of the Greeks, at the contemplation of unchanging truth. It is essentially inductive and experimental, and surveys the whole world of nature as it lives and moves. It is not satisfied with the establishment of a few abstract laws; it seeks to know all the facts about the world and to control the forces of nature. Moreover, it has been profoundly affected by the development of modern biology and the influence of the concept of evolution. The new sciences of living matter such as botany and zoology, and even non-biological sciences like astronomy and geology, are profoundly historical in spirit. They do not contemplate a static universe, but an evolving process in which the time factor is of primary importance.

And, on the other hand, modern history is no longer satisfied with rhetorical narrative or moral criticism. It seeks to understand the past rather as an organic process than as a mosaic of isolated facts. It tends to pay less attention than in the past to the superficial activity of politicians and diplomatists and more to the action of the permanent social and economic forces that determine the life of peoples. Above all,

it is coming to accept the new concept of Culture which has been brought into currency by the anthropologists. It recognizes that the state is not, as the nineteenth-century historians believed, the ultimate social unit and the final end of historical study. The cultural unity is both wider and deeper than that of the state. It is not an intellectual abstraction or a by-product of the political process. It is itself the fundamental social reality on which all the other social phenomena are dependent.

History is, in fact, whether consciously or unconsciously, becoming the science of social development; not merely the science of the past, but the science of the whole human culture-process in so far as it can be studied by documentary evidence. Thus the old opposition between science and history is being done away and history is being brought into increasingly intimate relations with the other social sciences, and above all with sociology. History and sociology are, in fact, indispensable to one another. History without sociology is "literary" and unscientific, while sociology without history is apt to become mere abstract theorizing.. Hitherto the greatest weakness of sociology has been its indifference to the facts of history. It has tended to manufacture a history of its own which will be the obedient servant of any theory it happens to propound. It is hardly possible to open a modern sociological treatise without coming across historical "facts" that are unknown to the historians and dogmatic solutions of historical problems which the historians themselves approach with the utmost diffidence.

This is the inevitable result of the mutual distrust between history and sociology and the attempt of each of them to assert its own independence and self-sufficiency. In reality sociology and history are two complementary parts of a single science—the science of social life. They differ, not in their subject matter, but in their method, one attempting a general systematic analysis of the social process, while the other gives a genetic description of the same process in detail. In other words, sociology deals with the structure of society, and history with its evolution, so that they are related to one

another in the same way as general biology is related to the study of organic evolution; neither can attain its end without the help of the other. Thus a sociological study of Greek culture would concern itself primarily with the organic structure of Greek society—with the city state and its organization, the Greek family and its economic foundation, the functional differentiation of Greek society, the place of Slavery in the social order, and so forth; but all these elements must be studied genetically and in relation to the general development of Greek culture on the basis of the material provided by the historian; while the latter, on his side, requires the help of the social analysis of the sociologist in order to interpret the facts that he discovers and to relate them to the organic whole of Greek culture, which is the final object of his study. It is for the sociologist to define the form of a culture and for the historian to describe its content.

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Actually, however, the sociologists have accomplished very little in this direction. As we have seen, the discovery and the systematic analysis of the cultural unit has been due to the work of the anthropologists rather than of the sociologists. The latter have been apt to despise such comparatively modest tasks and have aimed at something much more ambitious. From the beginning Sociology has been haunted by the dream of explaining social phenomena by the mathematical and quantitative methods of the physical sciences and thus creating a science of society which will be completely mechanistic and determinist. The path of sociology is strewn with the corpses of defunct systems of "social physics," "social energetics" and "social mechanics," and their failure does little to discourage fresh adventures. Such systems have little use for history or for social reality; they content themselves with generalizations that have no significance and with "laws" which are nothing but false analogies. Thus one writer maintains that social association is a variety of "the law of molecular gravitation" (Carey), another that culture is nothing but an apparatus for the transformation of solar

energy into human energy (Carver and Ostwald), while Winiarsky argued that social change proceeds according to the laws of thermodynamics. Such extravagances explain the distrust shown towards sociology by the historians, for their experience of the complex reality of the social process makes them naturally hostile to the crude simplicity of pseudo-scientific generalizations.

Yet, on the other hand, it is equally impossible to understand the life of man and society without the help of the natural sciences. In a thousand ways human life is conditioned and determined by material factors, and there is a legitimate materialism which consists in the definition and analysis of these relations. History by itself is not enough, for it is impossible to understand a society or a culture in purely historical terms. Underlying the historical process and the higher activities of civilized life there are the primary relations of a society to its natural environment and its functional adaptation to economic ends. The sociologist has to study not only the inter-social relations of man with man, but also that primary relation of human life to its natural environment which is the root and beginning of all culture. Here sociology approaches the standpoint of the natural sciences and comes closer to the biologist than to the historian, for the study of a society in its mutual relation with its geographical environment and its economic activity has a real analogy with the biologist's study of an organism in relation to its environment and its function.

The application of this "biological" method to the phenomena of society was the work of Frederick Leplay, who more than any other sociologist may be regarded as the discoverer of a scientific method of social study. In this respect he compares very favourably with his more famous contemporaries such as Marx, Spencer and Buckle. He succeeded in giving an economic interpretation of society which avoids the one-sided determinism of the Marxian hypothesis; he showed the influence of geographical factors in social life in a far more exact and scientific way than Buckle or Ratzel, and he provided a biological interpretation of society which

had nothing in common with the semi-scientific, semi-philosophical generalizations of writers such as Herbert Spencer. Leplay took as his unit the study of the family in its concrete geographical and economic circumstances and analyzed its social life and structure in terms of Place and Work. His great work, *Les Ouvriers Européens,* which appeared in 1855, contains a detailed study of thirty-six typical workers' families chosen from every part of Europe from Eastern Russia to the North of England and from every stage of culture from the Tartar herdsmen of the Steppes to the artisans and factory workers of Western Europe.[1] He studied these, not at second hand, through statistics and blue-books, but by the direct observation of their way of life and by a meticulous study of their family budgets, which he used as a basis for the quantitative analysis of the facts of family life. Leplay's method of social analysis affords an insight into just those fundamental social realities which so often escape the notice of the historian and the student of politics; but though it provides a genuinely scientific method for the study of society, it is not an exhaustive one. It required to be completed by a similar study and analysis of the other social units besides the family—the rural community, the city with its region, and the people and the State, and finally by an historical analysis of the social development and the cultural traditions of the society as a whole. Owing to his concentration on the family, Leplay and his school tended to over-estimate the importance of the economic and geographical factors and to neglect the contribution of history. Not that Leplay was in any sense a materialist. He avoided the pitfall of naturalistic determinism which has been the downfall of so many sociologists, and fully realized the importance and the autonomous character of the moral and religious element in social life. But he conceived this in a static form, as an invariable which governs social life from outside without entering into it.

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[1] These were a selection from the 300 monographs that he had actually prepared.

But a culture is not merely a community of work and a community of place; it is also, and above all, a community of thought, and it is seen and known best in its higher spiritual activities, to which alone the name of Culture was first applied. It is impossible to understand or explain society by its material factors alone without considering the religious, intellectual and artistic influences which determine the form of its inner cultural life.

Even if we consider society in its simplest form—the family—we still find these factors intervening in a decisive way. Not only do the religious and moral beliefs of a society always affect the structure and life of the family, but in some cases, as in China and in classical antiquity, the family was itself a religious unit and its whole life was consecrated by religious rites and based on religious sanctions.

It may be said that it is not the business of a sociologist to concern himself with religious beliefs or philosophical theories or literary and artistic traditions, since they lie outside his province and are incapable of scientific definition or quantitative analysis; yet, on the other hand, it seems absurd for him to study the physical environment of a society and to neglect the spiritual forces that condition its psychic life. The primary task of sociology is, no doubt, the study of the social *structure*, but this structure, on the one hand, rests on the material foundation of geographical environment and economic function, and, on the other, is itself the foundation of a spiritual superstructure which embodies the higher cultural values. If we isolate society from its material body and its cultural soul, we have nothing left but an abstraction. To see the Greek city, for example, in its social reality we must view it at once as a product of the earth and as an embodiment of Hellenism, like Erechtheus, the hero-king of Athens, who was the child of the Earth Goddess and the foster-son of Pallas Athene.

The intrusion of these qualitatively distinct categories or orders of being into the sociological field is a great stumbling-block in the social sciences. The natural scientist has a completely homogeneous material in the material phenomena

that he investigates; so also has the philosopher in the region of ideas; but the sociologist has to deal impartially with material and spiritual factors, with things and ideas, with moral and economic values, with all the multifarious experience of the two-sided nature of man.

Sociologists have always been conscious of this problem, and the spectacle of the brilliant results attained by physical science in its uniform field of study has often tempted them to find a way out of their difficulties by an arbitrary or one-sided simplification of their data. There is something very attractive about a "simple" explanation of the social process which treats the relation of the different factors as one of simple causal dependence and regards one of them as absolute and the rest as secondary derivations from it.

The most popular type of "simple" explanation is, of course, the materialist one, which attempts to deduce the whole social process from economic or geographical or racial factors, and relegates the cultural superstructure to a lower plane of reality as a subjective reflection of material conditions. The classical example of this is the Marxian theory, which reduces both history and society to their economic elements and regards the spiritual element in culture as secondary and derivative. In the words of Marx, "the mode of production in material life determines the character of the social, political and spiritual processes of life. It is not the consciousness of men that determines their existence, but their existence that determines their consciousness . . . with the change of the economic foundation the entire immense superstructure is more or less rapidly transformed."[1]

Now the error of this method of interpretation does not consist in the view that the ideological aspects of culture have a material basis in the economic life of society, but in the assertion of an absolute causal dependence which denies the independent significance of the spiritual factor in society. On the one hand, the concept of culture is arbitrarily impoverished by being emptied of all the values that are not explicable in economic terms, and on the other the economic

[1] *Zur Kritik der Politischen Oekonomie.* Intr.

category is arbitrarily expanded in order to include a whole series of non-economic elements.

This fallacy is not peculiar to the Marxists; we find it equally in the theories that profess to explain the whole development of culture on racial grounds and which use the Aryan race or the Nordic type as the *deus ex machina* of the historical process. Such theories explain everything, but also they explain nothing; they are like the conjuror's hat, which is equally capable of producing a cabbage or a white rabbit, as the occasion demands.

At the opposite pole to these materialistic simplifications is the idealist simplification which deduces the social process from the spiritual element in culture. To Hegel and his followers History is the progressive self-manifestation of absolute Mind. Each culture or people is a successive proposition in the process of a cosmic dialectic, and the material aspects of culture are merely the embodiment of the immanent idea. Such theories are now almost entirely discredited; nevertheless, we must remember that they played an essential part in the development of their apparent opposite—the dialectical materialism of Marx. Moreover, although the historical panlogism of the Hegelians is looked on by sociologists today merely as an historical curiosity, its elder rival, the rationalist idealism of the Liberal Enlightenment, still preserves its prestige in spite of all the ridicule and argument that have been directed against it from the time of Burke and de Maistre to our own days. This Liberal idealism is marked by a belief in an absolute Law of Progress and an unlimited faith in the power of reason to transform society. Concepts such as Liberty, Science, Reason and Justice are conceived, not as abstract ideas, but as real forces which determine the movement of culture, and social progress itself, instead of being regarded as a phenomenon that requires explanation, is treated as itself the efficient cause of social change. Beliefs of this kind are religious rather than sociological, as Pareto has shown in the incisive criticism of his *Trattato di sociologia generale*. Nevertheless, they still exercise a powerful influence on popular sociology, and they are not altogether

absent from the theories of such distinguished modern writers as the late Professors L. T. Hobhouse and Lester Ward.

There remains yet a third type of explanation, which seems at first sight to offer a more satisfactory way of approach than either the materialistic or the idealist theories, since it professes to explain social phenomena in purely social terms. Nevertheless, this "sociologism" suffers from precisely the same defect as the other "simple" theories. For if, on the one hand, we attempt to study social relations apart from their material foundations and their cultural value, as the "formal" school of sociologists represented by Simmel and Von Wiese wish to do, we empty sociology of its content and are left with a series of logical abstractions. If, on the other hand, we reduce both the material and the spiritual element in culture to purely social sources, we are guilty of just the same unscientific simplification as the adherents of economic determinism or Hegelian panlogism. No doubt the exponents of this theory, such as Emile Durkheim, give a much wider analysis of the spiritual element in culture than do the materialists, and, in particular, they do full justice to the importance of the social function of religion, but they do this only by hypostatizing society into an independent spiritual power: not only is the social the cause of the religious, but the two are identical, and the Divine is the social sublimated to an ideal plane. This is not a scientific explanation, but an amalgamation of religion and society by means of an illegitimate substitution of one category for another.

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The fact is that all "simple" explanations are unsatisfactory and irreconcilable with scientific sociology. It is impossible either to make society its own cause or to deduce social phenomena exclusively from material or spiritual ones. As Pareto has shown, the essential requirement of sociological method is to abandon the idea of a one-sided relation of causal dependence between the different factors and view the social process as the result of a complex series of interdepen-

dent factors. Material environment, social organization and spiritual culture all help to condition social phenomena, and we cannot explain the social process by one of them alone, and still less explain one of the three as the cause and origin of the other two.

Although the sociologist must take account of the geographical, economic and intellectual or religious conditions of a social culture, he has no more right to lay down the law on philosophy or theology than on geography or economics. But though this is generally recognized in the case of the science of nature and even the other social sciences, sociology has been far less scrupulous in dealing with the sphere of the higher spiritual values. It is often argued that these are a product of the social process, since there can be no spiritual culture apart from society, and therefore " spiritual sciences " (Geisteswissenschaften) can claim no scientific autonomy.

This, however, is the result of a naïve confusion of thought. All the spiritual activities that appear in culture—religion, philosophy and science—possess their own formal principle. They are not mere functions of society, but have their own ends, which in a real sense transcend the social category. The sociologist, no doubt, is justified in studying a religious belief in its influence on society, but the theologian does not judge his belief or theory in terms of social value, but in terms of religious truth.

So, too, with scientific ideas; Durkheim has given a most ingenious exposition of the way in which man's ideas of time and space have a subjective basis in the rhythm and order of social life. But the scientist himself aims at transcending all such social subjectivism and attaining some absolutely objective standard of measurement. In other words, the more " anthropomorphic " a scientific idea is, the more interesting it is to the sociologist and the more worthless it is to the practitioner of the particular science in question.

Actually, however, there is little danger—at least, outside Russia—of the Sociologist dictating to the naturalist or attempting to "sociologize" science as a whole. But there is, as we have seen, a real danger of the sociologist trespass-

ing on the territory of the other Geisteswissenschaften and attempting to play the part of a theologian or a philosopher.

A sociologist is, of course, quite within his rights in arguing that religion is necessary to society, or the reverse, or that a particular religion is beneficial or harmful to a particular society. For example, he might conclude from the study of ancient civilization that the introduction of Christianity was fatal to the institutions of the city state and the tradition of Hellenic culture. But this would not justify him in drawing conclusions about paganism or Christianity *qua* religion. That is a matter for the theologian.

When Professor Ellwood, in his well-known book *The Reconstruction of Religion,* argues that religion is necessary to society and performs important social functions, he is reasoning as a sociologist, but when he goes on to "reconstruct" religion and to propound a new form of socialized Christianity, he is exchanging the rôle of a sociologist for that of a theologian.

It is no matter whether the religious theories that we propound are materialist or supernaturalist, rationalist or mystical, theistic or humanitarian. The point is that when we once begin to make a religion or to discuss purely religious values, we enter the theological region and speak as theologians, not as sociologists.

Even since the time of Comte there has been a constant succession of theological sociologies which aim, not at the study of actual societies or actual social phenomena, but at the reformation of society on the basis of a new religious ideal. These attempts have been almost uniformly unsuccessful, for they are vitiated by an inherent confusion of method. They try to produce a synthesis between religion and sociology, and they succeed only in creating a hybrid monstrosity that is equally obnoxious to scientific sociology and to genuine religious thought.

I do not say that it is impossible for a sociologist-philosopher-king to plan the organization of society deliberately on the basis of general philosophical principles. Something of the kind was, indeed, accomplished by the Tokugawa

Shoguns, who gave Japanese culture a conscious unity like that of a work of art. But they could appeal to the prestige of the Confucian tradition—that is to say, to an inspired sociology that had a genuine religion and a divinized sage behind it. If Iyeyasu had manufactured a new religion of his own to meet a purely social need, it is very unlikely that he would have been as successful as he was.

The sociologist who creates a religion of his own for sociological purposes is just as unscientific as if he were to invent new anthropological or geographical facts to suit his theories.

As sociologists we have to accept the existence of this independent order of spiritual truths and values and to study their influence on social action. Whether society requires a religious foundation; what is the actual working religion of our particular society; how far material and social factors affect religious beliefs and philosophical points of view;—all these are questions for our study. But the objective intellectual validity or spiritual value of religious doctrines and philosophical theories lies entirely outside our province.

It does not, of course, follow that these questions are in themselves insoluble or otiose. There is no reason for the sociologist who observes the limits of his science to write off everything beyond it as unreal or as matters of arbitrary speculation. No doubt the study of social phenomena in their complex irrationality has often led sociologists to prefer the despairing scepticism of a Macchiavelli or a Pareto to the self-confident dogmatism of the idealists. Nevertheless, if such an attitude is justifiable it must be justified on philosophical grounds. The sociologist as such does not possess the necessary data for making a universal judgment of this kind. Here again he must follow the example of the historian, who no longer seeks to use history in order to justify his political or religious opinions, but who seeks to understand the beliefs of the past as a means to understanding its history.

This method of sociological analysis can be applied to practically every social phenomenon, even to those which seem at first sight to be entirely non-spiritual in character. For example, Max Weber, one of the first modern exponents

of "a sociology that understands" (*verstehende Soziologie*), has shown how the development of Capitalism is not to be explained as a purely economic process, but has its spiritual roots in a new religious attitude towards industry and saving that grew up in Protestant Europe after the Reformation. On the other hand, there are other phenomena which seem at first sight to be purely religious and yet have their basis in economic or social causes.

Thus every social type or institution is the result of the complex interaction of a number of factors that are qualitatively distinct and can never be reduced to simple unity. Take for example the social type of the Samurai in Japan, a type which seems sociologically simple enough, since it represents an obvious social function in Japanese society. Nevertheless, in order to understand it, it is not enough to study the historical evolution of Japanese feudalism and the economic structure of Japanese society. The Samurai type is also the embodiment of a whole complex of moral ideas and religious beliefs—native, Confucian and Buddhist—some of which have a very remote relation both to Japan and to the military tradition. And the ethical code or cultural ideal that is the outcome of all this is not merely a matter of historical interest; it is an abiding element in the Japanese social tradition, and without it it is impossible fully to understand either Japanese politics or Japanese thought.

But if Sociology needs the help of philosophy and theology in order to understand the spiritual elements in the social process, it also renders services to them in return. We cannot understand an idea unless we understand its historical and social foundations. We cannot understand the Greek institution of citizenship unless we study its spiritual foundations in the religion of the city and the family. But on the other hand we cannot understand the Greek philosophical ideal of political liberty and its ethical ideal of "magnanimity" without a knowledge of the political life and the social structure of the Greek state. And even our modern ideas of liberty and democracy are not unaffected. The philosophers of the eighteenth century interpreted the classical ideas of liberty,

democracy, etc., in an abstract and unsociological way, and consequently they misinterpreted them, and this misinterpretation was not without its influence on their philosophical thought.

In the same way the theologians have often failed to recognize the social and economic elements in religious phenomena, with the result that they have confused religious and sociological values and have allowed a racial or economic opposition to translate itself into a religious conflict. Most of the great schisms and heresies in the history of the Christian church have their roots in social or national antipathies, and if this had been clearly recognized by the theologians the history of Christianity would have been a very different one.

A scientific method of sociological analysis may serve the same purpose for society as a psychic analysis may accomplish for the individual by unveiling the causes of latent conflicts and repressions and by making society conscious of its real ends and motives of action. The actual tendency of practical politics, especially in democratic countries, is unfortunately just the opposite, since they invest such conflicts with a halo of idealism and thrive on sociological misunderstandings.

This is the more regrettable because the modern state is daily extending its control over a wider area of social life and is taking over functions that were formerly regarded as the province of independent social units such as the family and the church, or as a sphere for the voluntary activities of private individuals. It is not merely that the state is becoming more centralized, but that society and culture are becoming *politicized.* In the old days the statesman was responsible for the preservation of internal order and the defence of the state against its enemies. Today he is called on to deal more and more with questions of a purely sociological character, and he may even be expected to transform the whole structure of society and refashion the cultural traditions of the people. The abolition of war, the destruction of poverty, the control of the birth-rate, the elimination of the unfit—these are questions which the statesmen of the

past would no more have dared to meddle with than the course of the seasons or the movements of the stars; yet they are all vital issues today, and some of them figure on the agenda of our political parties. It is obvious that the solution of these problems calls for all the resources of sociological science—even supposing that science was in a much more advanced state than it actually is; yet the unfortunate politician is expected to provide a solution by his common sense enlightened by a cloudy mixture of economic materialism and moral idealism. We can hardly wonder at the popularity of Marxian Socialism, for that at least has a sociology of a kind, though it is elementary and one-sided.

A sociology which disregards its proper limits may create Utopias, but it cannot help the statesman in his practical tasks. What we need is a scientific sociology which will transform the art of politics in the same way that the modern sciences of biology and physiology have transformed the art of medicine. In the task of restoring spiritual order and social health to our distracted civilization sociology has, as Comte realized, an essential part to fulfil. But it is to be achieved, not by usurping the functions of philosophy and theology, as in the Positivist synthesis, nor by ignoring moral and spiritual values, as with Marx. It must recognize at once the determination of natural conditions and the freedom of spiritual forces, and must show how the social process embraces both these factors in a vital union like that of the human organism.

Such a sociology alone can prepare the way for the coming of a new applied science of politics which would plan the City of Man, not by the rule of abstract ideas and visionary theories, nor in terms of material size and wealth, but as a true *community*.

SCIENCE AND THEOLOGY

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THE history of theology shows that while theologians are often distracted from their proper business by contemporary scientific opinion, the principles on which it rests and the methods appropriate to it are different from those of the physical sciences. Science, in the modern and confined sense of the word, may be said to date from the sixteenth century, and it has been defined as a well-criticised body of descriptive knowledge based on observation and experiment. The word observation implies that the subject matter is visible or of the sort that could be made visible, and the word experiment, again, implies that one can bring to bear certain methods of investigation and verify their success by sensible experience. It took man a long time to find out what these methods were; once discovered they proved to be a more potent art than that of Prospero to bring a mutinous nature to heel. Various reasons, however, among which their rapid success must be counted, conjoined to hide the fact that they were not suited to all realms of knowledge and that their very success was gained through sacrifice. To the detriment of philosophy and the dismay of certain theologians the truths contained in the old philosophies based on Plato and Aristotle and the methods followed by them were set aside. Tired with the constant appeals to the authority of Aristotle and intoxicated with success men like Bacon declared that they would "no longer be kept dancing in rings, like persons bewitched, but our range and circuit will be as wide as the compass of the world." The coincidence, therefore, of a decadent scholasticism and a new method, which by its initial successes seemed to have the world at its feet, brought confusion into the ranks of the

philosophers and the theologians, and many of the latter, to use another image of Bacon, were diverted by science from their true course like the runners by the golden apples of Atalanta.

The effect of this reaction from the old was to bring metaphysics into disrepute and to bestow on the mathematical sciences the exclusive right to knowledge. That theology was involved in the downfall of metaphysics was not fully realised for some time. The ultimate consequences of a revolution usually take time to be assimilated, and so it is not surprising to find that the seventeenth century was intensely religious and that great physicists like Newton were not aware of the conflict between their faith and the marvellous mechanical world of their theories. Moreover, many religious thinkers—consciously or unconsciously in accordance with the trend of the period—abandoned thought as an aid to religion. Faith, this group proclaimed, echoing the words of the chief of the Reformers, is an experience, an assurance of confidence; "reason is directly opposed to faith, and so one should let it go; it should be slain and buried by believers." Those, therefore, who regarded the Sorbonne as "a damned synagogue of the devil" were not likely to contest in the name of religion and theology the claim of the mathematical sciences to be the exclusive proprietors of knowledge. And, as if this were not enough, two verdicts of distinguished philosophers came to be accepted, despite their differences, as the law on the relations of science and theology. The first was that of David Hume. His verdict relied on the evidence of the Cartesian philosophy and the principles professed by contemporary science, and it came to this, that if sensation be equivalent to knowledge, then all such conceptions as God, substance, and cause must be put aside as illusory and we must content ourselves with a world of sensation and a subject which feels and is like a target dotted with experiences. Such a verdict, of course, left no room for theology nor even for science, as no meaning could be given to inductive method nor any explanation of its success. The scientists, however, did not apply the lesson to themselves;

they saw only that theology had been sentenced to death. It needed a second philosopher, Kant, to grasp the extent of the damage and revise the verdict of Hume. Science, he maintained, was not an affair of sensation alone, but of a happy conjunction of it with thought. Neither sensation nor thought by itself could be productive; the former was too feeble, while the history of metaphysics showed that thought by itself was always sterile. Human nature, being composed of mind and body, could not advance in knowledge without the aid of both, and so it was well adapted to the understanding of the visible sensible world and incapable of knowing and criticising what lay beyond it. By this means Kant justified science at the expense of theology but not of religion, as he thought; for he went on to say that if science could not find a God, neither could it criticise God if he existed, and that he did exist he thought was certain, in that he was a necessary postulate for moral experience and ideals.

This olive branch offered by Kant did not bring the lasting peace that he had hoped. It tended to obscure still further the principles on which theology rested and gave an exaggerated estimate of the mathematical sciences. No longer would philosophers use the classical arguments for the existence of God, as they were supposed to have been invalidated by Kant's criticism of them. Those who refused to accept the scientific account of the universe as complete and exhaustive had recourse more and more to some special kind of experience which was called religious. It would be impossible to give a just appreciation of the variety of forms which this experience has taken; nor is it altogether necessary, as extremist views are now being laid aside and an attempt being made to widen the term so as to include what is best in thought as well as in feeling. The formulæ of Hume and Kant are, in fact, undergoing revision at the hands both of the religious thinker and the scientist. The latter has indeed continually passed beyond the limits laid down by Hume. In the nineteenth century men like Huxley and Tyndall were stirred by a religious, if anti-theological fervour. They

wanted a view of life. "There is grandeur," wrote Charles Darwin, "in this view of life with its several powers, having been originally breathed into a few forces or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved." This lure of philosophy has become more and more potent with the coming of the revolutionary changes in science and the resulting alarums and excursions. The physicist in his laboratory may pray to be relieved of the spying of reporters and the real or bogus interest of his philosopher friends, but in the end he does not resist the appeal to say a word at the British Association or talk round theology in Gifford lectures. And in the end he can hardly do otherwise, for the classical principles of physical science have become so involved and so often checkmated by experiment that the very foundations have come to be questioned. Experiment is at loggerheads with observation, and such a situation provides a happy hunting ground for the philosopher and theologian.

I need not insist on this change of front among the scientists. It will be enough to point to what is called the new principle of indeterminacy and the danger of scientists losing their heads and thinking that they have made the first and scientific discovery of free will; to the confession of theism by J. S. Haldane, of a mathematical or architectural source by Jeans, of "one systematic fact, which is the antecedent ground conditioning every creative act" by Whitehead. These examples could easily be supplemented by quotations from the writings of such diverse thinkers as Lloyd Morgan, Julian Huxley and Eddington. They are not at all agreed as to the means of passing beyond science or what God should signify, and few give, as Whitehead does, a sustained criticism of the foundations of science and attempt to forge a new philosophy out of the criticism. The majority, having accepted a naïve realism and having worked within the framework of the philosophy of Descartes and Hume, have been fought to a standstill by nature. In

the old view, now entirely surrendered, substances were thought to move about in space unchanged; it was based on observation and assumed that fundamentally the real world must be microscopically what ordinary objects were macroscopically, that atoms and electrons were like billiard balls and always so. As Eddington says: "the Victorian physicist felt that he knew just what he was talking about when he used such terms as matter and *atoms*. Atoms were tiny billiard balls, a crisp statement that was supposed to tell you all about their nature. . . ." Hence, starting with observation, the scientist proceeded to make hypotheses on the likeness of the observed object, omitting, of course, all that was irrelevant. A change came about when the hypothesis failed to work, and the scientist felt himself forced to picture nature structurally as a physico-spatial-temporal real which must be treated very severely by means of mathematical equations. This meant that he had to start from the microscopic to the macroscopic and not vice versa, and at the present moment it has landed the scientist in agnosticism. "Now we realise that science has nothing to say as to the intrinsic nature of the atom. The physical atom is like everything else in physics, a schedule of pointer readings" (Eddington). For the moment, that is, one school of scientists has passed a self-denying ordinance. So far as they are concerned, as has been remarked by one of them, a theory that all changes are due to the influence of demons is just as feasible as any other. That scientists do not take this hypothesis seriously is, as Einstein has remarked, "a question of good taste"; they like neatness, and so "to comprehend signifies a reduction in the number of the axioms." We cannot hope to know, or at least have no means of knowing at present, how nature works. All our experiments are bound to deform it and in a constantly altered world there is no meaning in asking whether the principle of causality or uniformity holds true of it. "That it is valid statistically experience leaves no doubt, but so are the formulæ of the life insurance company" (Lindemann).

Now there must be something in the scientific method

which is accountable for such conclusions, and I do not think that it is far to seek. Bukharin, in his address in 1931 to the delegates of the U.S.S.R. on the Theory and Practice from the Standpoint of Dialectic Materialism, put his finger on it. "The crisis in modern physics—and equally in the whole of natural science, plus the so-called mental sciences (Geisteswissenschaften)—has raised as an urgent problem, and, with renewed violence, the fundamental questions of philosophy: the question of the *objective reality of the external world,* independent of the subject perceiving it, and the question of its *cognisability* (or, alternatively, non-cognisability.) Nearly all the schools of philosophy, from theologising metaphysics to the Avenarian-Machist philosophy of 'pure description' and renovated 'pragmatism,' with the exception of dialectical materialism (Marxism), start from the thesis, considered irrefutable, that 'I' have been 'given' only 'my' own 'sensations.'" As evidence for this statement he quotes, besides Mach and Avenarius, K. Pearson, Bergson, James, Vaihinger, H. Poincaré, B. Russell, Ph. Frank, M. Schlick and R. Carnap. That this diagnosis is right can scarcely be doubted. Einstein, for instance, when he tells us that "to understand is to draw one incomprehensible out of another" is relying on the assumption that we begin with sensation alone and that what thought does is to link together the sensations by means of some descriptive theory. The same view is very clearly expressed by Lindemann. "The primary data which man shares with other animals are the experiences we call sense-data. Thanks to his memory, each individual can compare such experiences with previous ones. As civilisation has advanced mankind has been more and more concerned to collect such sense-data into a system subsuming the experiences which had been undergone and into which each fresh experience fitted. Any system capable of fulfilling these conditions is satisfactory; which one is preferred can be merely a matter of individual taste."

What, then, is the position of the theologian in the light of the teaching of modern science? All depends on whether

he accepts or not the claims and presuppositions of that science. There are some who are thankful that science is now taking up such an agnostic attitude; the mist is no longer in the air concealing the heavens, but covering the ground. And if this new hope seems to many, including myself, precarious, it must be remembered that not only the theologian but the scientist also has been glad to avail himself of the present plight of physics to invoke religion. In genuine humility some have turned from their so-called fictions or descriptions to a belief founded on revelation or religious experience or mysticism. In the first case, the belief takes the form of fideism, a view often taken up in the past and quickly dropped because it interferes with the longing of a man to think out his origin and destiny. Such a belief has given comfort to many, but I think that it must necessarily be episodic and not permanent, as man cannot forswear for a long time all thought on his origin and destiny, even though divine revelation is surrounded, as by a Karl Barth, with an atmosphere of apocalypse and prophecy. As to experience and mysticism, much depends on what is meant by these terms, and one of the hopeful signs of the times is the amount of careful study and analysis that has been given to them. Owing to the course which religion and science have followed since the Reformation, experience has unfortunately been assumed to be in some ways irrational or super-rational, and this view has had support from philosophers like James and Bergson. I am sure that this way of religion is a cul de sac, and there are welcome signs that this is being recognised. Books such as *Philosophical Theism* by Dr. Tennant pay scant attention to the argument from experience. Dean Inge and Dr. Matthews are less hard-hearted, but they, too, protest against the uncritical acceptance of experience as the one guarantee of religion. After all, in no other sphere of human activity or passion are the truth and value of the feelings and intuitions and experience judged by their evidence alone, and religion can carry no conviction to one who wishes to ascertain the grounds of its truth, if it relies on such a subjective standard.

Without deserting the test of experience, some do try to make it less subjective. One way is to borrow the scientific method of verification. They say that here undoubtedly is an experience which cannot be taken into account by science. It should not, however, for that reason be dismissed, for if we look at its place and history in human life, we see that it is responsible for some of the highest values and that life would be infinitely poorer were it taken away. It cannot, therefore, be false or illusory. It will be noticed that the same argument is here being used for religion as has been used in the defence of morality and art. A physical world as described for us in terms of physics leaves no room for quality, for beauty or goodness; man, therefore, must be in some other way in contact with them, and it is fair to put the religious sense alongside that of the aesthetic and the moral. The trouble with this argument is that it still hides itself under vague titles, and many have cast doubt on the precise object of aesthetics, questioning whether it be wholly objective. This difficulty might be overcome if, as Otto has maintained in his *Das Heilige*, it could be shown that mankind possesses a sense of the divine. Valuable as Otto's contribution is to theology, I do not think that his analysis of the Holy and the 'numinous' is above criticism, for we are left at the end still wondering what precisely is the sense, whether it is chiefly emotional or intellectual, and if it is intellectual, how God can be said to be apprehended directly. Dr. Matthews and others regard this view as an improvement on that of Schleiermacher, who held that religion is a "feeling of absolute dependence," and Dr. Matthews himself prefers the expression of Boutroux, "the Beyond which is within," and looking for some deep and permanent needs of the human spirit to explain man's religiousness, finds them in "two salient and ineradicable needs of the spirit . . . the need for unity and the need for the substantiation of value."

Thus we see that the theologians belonging to the school of experience are moving to a sounder position than that held formerly when science was suppposed to hold exclusive

rights over reason and religion was referred to an irrational or super-rational experience. It cannot be said, however, that they are out of the wood yet, and there is one strange assumption which even now remains unquestioned. It sticks out in the words of Dr. Matthews when he looks "for some deep and permanent needs of the spirit." Here, we notice, need is the criterion, and God and religion are brought into court to have their claims settled on the one count, whether I want them or not. This brings out the revolutionary change in theology which passed almost unnoticed. The old theology began with God and then proceeded to argue from His nature to what must be the right relation of man to such a being, and this it defined as religion; now we begin with what we should desire, with religion as a human value, and cut a pattern of God to suit our desires. This may be a legitimate way of proceeding, and if, of course, we are afraid of intellect in religion it may be thought to be the only way, but it remains surely a very dangerous one; it suggests, in fact, that a god, if he exists, may take his importance from us and be like a sleeping Endymion or impotent until we entice him into life by our calls upon him. Acting on this belief theologians have made a close study of the common motives which lie behind all the various manifestations of religion, and I should say that the chief value of such work lies in this, that it has taught us much about the nature of man; but it is not so clear that it will suffice for an understanding of religion. The old method was to take the data of any experience and to submit them to the test of reason; philosophy was considered to be such a reflection and it offered us an enlightened and austere vindication in systematised form of all that was given, no matter how, in experience. Just as in science, physical or biological, medical or psychical, the data cannot be taken at their face value but must be sifted and approved of by reason, with the help of inductive or deductive methods, so in religion, save that theology might have to rely more on deduction than on observation and experiment. The disinclination to follow this way can be traced back to the rift made in the

past between reason and faith (of which I have already spoken) and the anxiety of so many theologians to remove religion from the embrace of that mechanical determinist philosophy which dominated Europe for a while and was supposed to be the supreme work of the human mind.

The time seems now to have come when both the scientist and the theologian are beginning to talk a similar language instead of looking at each other from a distance. The theologian is, as I have explained, deserting the ground of mere experience and not only has science forsworn its pretensions to an exclusive knowledge of reality, but it is in danger of moving too far in the opposite direction. The most promising sign is not the scepticism of a Lord Russell, nor the overturning of the tables of science and philosophy alike by a Wittgenstein, nor even the tentative efforts at a theology made by Sir James Jeans, but the thorough overhauling of scientific presuppositions by Whitehead. The difference between these two latter is that Jeans still takes as the standard of all thinking about reality mathematics and not metaphysics, and so permits only a God who can be addressed in mathematical terms, whereas Whitehead, having demolished this assumption of Jeans', is able to go ahead with a new philosophy of nature and a much more comprehensive account of God. This, I think, is a vital difference, as great, in fact, as that which divided Plato with his intelligible world from the atomists, and one, too, which gives scope for a theology properly so-called.

The line of thought newly opened up by Whitehead is one which was followed by the older tradition of theology, and it matters little whether one agrees with his conclusions or not so long as the significance of his point of view be grasped. The great successes gained by the introduction of the mathematical methods at the Renaissance concealed the fact that that victory was gained at a price. *Impera* indeed but *divide*, and this division meant the choice of an abstraction, the sacrifice of the hope of knowing the world wholly and intuitively. Even so, all might have gone well if the nature of this sacrifice had been kept in mind, but success

suggested contrast with slow-moving metaphysics, and the philosophers themselves fell under the spell of science. Hence it was laid down that our knowledge was confined to the sensible world, "that the primary data which man shares with other animals are the experiences we call sense-data." There are two mistakes here which are closely allied. Beginning with observation man is aware of a sensible something, a thing possessing extension and colour at least; but the secret of the success of man as a scientist was to ignore the thing and the quality of it and to concentrate exclusively on the one part of the object which was calculable and so reducible to "a system of measurable relations between countable x's." What was left over was first ignored and then in time came to be regarded as not falling within knowledge. Thus the first mistake arose, and the second was a corollary of the first, consisting in the erroneous idea that we knew only our sensations. Thus it came about that with one fell stroke the supreme distinctions between the noetic or intelligible world and the aesthetic or sensible world built up by Plato and his successors were destroyed. The truth, which it now concerns us most to admit, is that empiricism is in its last agony, that we start with reality, with sensible reality indeed, but still reality, and that herein lies an essential difference between man and the animal. Thought is not a temporal afterthought; it works by means of sense and in dependence on sense, but it is instantaneous in the composite act of man which tells him that he is aware of some sensible real thing. I should like to go on to show that no sound theory of what is called the universal can be given, unless we grant that the particular can never be given first and in isolation, but I must hurry on to give two consequences of this truth. The first is that on this theory an escape from agnosticism is provided for science. Trusting itself alone and with no roots in reality, no sooner do its results fail to work out than it despairs and calls itself a maker of fictions. If, on the other hand, science recognises itself as a legitimate abstraction within an act of knowledge which of its essence grasps the real, then it should expect to

progress alongside the real and to give a report which, if limited by abstraction and inadequate, is nevertheless drawn from that real and informatory about it. But it may be asked why are the methods of mathematical science employed at all and with such desperate zeal by man if, as I say, the mind transcends sense and looks out on the fields of reality as they are in their own nature? The answer to this brings us to the heart of the matter. It is true that the mind, being a mind, is able to glimpse the intelligible, noumenal world; it is able to traverse it from end to end and reconstruct its ultimate and far-reaching principles, but the vision, though bounded by the real, is nevertheless imperfect. There is only one spot on which it rests with comfort, the terra firma of the sensible. Kant was nearly right when he said that the mind needed the help of sense to escape from empty formulations. He wrecked his system when he went further and protested that we have no knowledge of the thing in itself. What he should have said is that we must have some knowledge, if we have knowledge at all and if empirical science is to stand, of the nature of reality, and that that must be eked out with the help of sense. If it be true that we are citizens of no mean realm of being, we have no intuition of it; we read its meaning through the veil of sense, through its appearances. Not that we first perceive appearances and then infer a reality; this may be necessary when we want to reach some particular cause or substance; but we always read through the phenomena something of the meaning and intelligible character of the universe. If also we are forced always to represent to ourselves what we know in terms of some image or material symbol, as we are proved to do by the very use of such words as apprehension, concept and understanding, we can transcend the limitation of the symbol and see that it signifies the intelligible though it represent the material.

Now if this correction of current assumptions be accepted, then the function of mathematical science can be elucidated and a way opened for a theology worthy of the name. The idea of man as a by-product of a vast mechanical system or

just a highly sensitive animal must end finally in a felo de se of man. But neither will the opposite extreme do, that all goes on in his mind or that he is the creator of values. The truth about him is both uplifting and humiliating; by reason of his mind he is, as Plato and Aristotle saw, godlike, and by reason of his limitations he has to look before and after, to use discursive reasoning, to work empirically for the most part. He can see dimly infinite distances, but he has to use his two feet to walk and explore them. The ancient preferred to sit still and satisfy himself with what he could see in outline, the modern has found out a substitute in the mathematical methods, which resemble an aeroplane, with all the limitations that come from looking down on a flat surface. (To save misunderstanding, let it be remembered that in this simile the distances are seen by sense, whereas the vision of reality and its outlines is of the intellectual order and therefore indefectible.) Both procedures are right, both requisite. Physical science tells us about the material world in so far as it is calculable, and one of the characteristics, though not the only characteristic, of physical being is that it is measurable and numerable; and again there are characteristics of the metaphysical world which are intelligible, and even if they have to be represented to ourselves, because of our natural reliance on sense, in sensible or anthropomorphic terms, we can be sure that we are knowing something of the nature of reality and we can, by a method to be explained later, rectify the limitation imposed upon us by our way of thinking.

The advantage of this theory of knowledge is that it brings within one sweep physical nature, the sensible world, man, and a possible highest order in which truth, goodness and beauty abide. There are no unbridgeable gulfs separating science from philosophy and philosophy from theology. The fatal sharp distinction first imposed on the modern world by Descartes in philosophy between *res extensa* and *res cogitans*, and by Luther in theology between faith and reason, is destroyed. Science is not based merely on sensation and it is not the only form of knowledge, and there is

no need to place this over-reliance on human experience and spoil supra-sensible knowledge by calling it mystical or supra-rational, or, in a less confident mood, subjective and anthropomorphic. The harm caused by so doing has been considerable, as might be illustrated by the history of such terms as substance, self, nature and even idea; but one example may suffice, that of cause. The scientist, starting with a confused notion of sense-experience, kept the notion of cause both because at first he pictured atoms as infinitesimal billiard balls and because he persevered, without being fully aware of it, with some of the old metaphysical notions. The more, however, the mathematical methods came into force and the more he took over the standpoint of Hume, the less pertinent did the idea of cause appear. Now it is claimed in many quarters that there is no need of it at all. That may well be because physical science has chosen an aspect of the real which can be treated without it; at any rate that is for the physicists to decide. But the persisting presence of the notion is due to the fact that cause does belong to the real order from which science has abstracted its subject matter. Even the philosophers, however, have been frightened of saying this because in the train of Descartes they have broken the chain which united together in some sort the world of sense and the world of intellect, the realm of quantity, quality, life and spirit. Hence they took their own experience of causality as subjective, as peculiar and doubtful, and considered that it would be anthropomorphic and illegitimate to transfer it to the physical world. And so arose the habit of speaking of logical connection as if it had nothing to do with connections in reality, and of laws of thought which ruled no kingdom of the world. Such a philosophy, thank heaven, is no better than a nightmare, and the truth is that our thought from the beginning takes its complexion from reality, and that just as it is impossible to think without using the category of ground and consequent, so it is impossible to think of reality without the principle of causality. That is not to say that cause is used in exactly the same sense of matter, of will and of God. There are various orders

within the real and the differences between them are not merely nominal; matter is not spirit nor spirit matter, and yet they are not wholly alien; they both exist and are something, and this unity is not just nonsense, a *flatus vocis* idly used. Even God falls within this dark majesty of being, and that is why our thought of Him touches reality, though from afar off. And so it is that we meet cause in every order of the real. The scientist confesses to this because his inquiry involves the questions, why and wherefore, and though by a self-denying ordinance he confines his further inquiry to phenomena and their succession, even there he stands on the brink of real causes and profits by the fact in the applied sciences. Human beings, again, know what self-determination is and see the analogy which exists between the world outside, their own bodily activities and their will; and lastly God fulfils in His own way completely the meaning of cause, for, whereas in nature and in ourselves the why and the wherefore had to be sought beyond the event and beyond our own existence and life, God is his own explanation; He requires nothing to support Him or render Him intelligible; He is complete and dependent solely on Himself; He is therefore cause in the fullest sense of the word.

It remains, now that the way has been opened to a science of theology, to show it at work. The modern way, as I have pointed out, is to begin with experience. In so far as that means that we can start with the fact that most, if not all, peoples have believed in the existence of a God or gods and held certain beliefs about them, it can be accepted. The task of theology is to scrutinise these beliefs and all relevant religious data and ask what validity they have. This procedure is common to all scientific inquiry, but there is this peculiarity about the data of theology, that the object of the belief is not sensible or visible and that it is bound up with values, even ultimate values. I do not mean, of course, that the gods have not often been pictured and imagined as visible. It is indeed a confirmation of my argument above about the nature of our thinking, that man has habitually tended to represent to himself the divine being in physical

shape, but it must be taken for granted for brevity's sake that God is by nature immaterial. Now, this being so, a free-thinker like Lord Russell is at liberty to suggest that religion is just a mode of escape from a frightening universe or animistic illusion or childish fancy. On his side the theologian must try to show that such a hypothesis does not fit the data, and if he believes in the possibility of philosophy he will be prepared to argue, from any positive datum his opponent may like to choose, that there must be a God, and will challenge the sceptic to find a flaw in his argument. This, I think, is the better method if it can be followed, as it leaves the field of hypothesis for strict argument. But, as already explained, it is not usually followed owing to the general distrust of the mind's power to extend beyond experience. Instead, we have arguments of the following kind. As a phenomenon, religion cannot be dismissed as unimportant. In the beginning it played a vital part in the life of the community; the early communities, so far from being confined in their thought to their immediate physical needs, are, if anything, too dominated by the sense of the preternatural and by religious beliefs. Nor is that religion just a mass of superstition; it is rather the vague conception of an "ocean of supernatural energy" and has for its root that sense of dependence from which all the highest manifestations of religion spring. "O You who possess the skies. I am living. I in you entrust my fate again alone upon the war path," as the Pawnee warrior sings. If, then, as the evidence seems to show, religion is the strongest force in the development and preservation of a culture, it must be taken seriously. We are all the more bound to do this when we regard its highest manifestations in the world religions and particularly in Christianity. An experience which can produce such high types of manhood as are to be found in the saints and bring before mankind such high values as the mystics speak of, must be given full measure in any worthy interpretation of life. And so it is that these experiences can be gathered together and given the status of a branch of knowledge which, if distinct in aim and method from that of the

sciences, deserves nevertheless to be included within a general philosophy of man and the universe.

The correct method to be followed in theology, what may be called the philosophic method as opposed to the scientific, may be explained in the following way. The scientist, dealing with a branch of knowledge, one carefully selected field of operation, one, moreover, so delimited as to suit his method of observation and experiment, is not concerned with general principles and truths which are antecedent to his study. He assumes what is necessary and only what is necessary to help him forward, and he is at liberty to make any hypotheses he likes so long as he can verify them. The philosopher and the theologian, on the other hand, have the duty of clarifying the first principles, of searching out what must be, if there is to be anything at all; and so the philosopher asks whether there can be any such thing as knowledge at all, wherein its nature exists, what is the relation of its object to it, what different kinds of objects there can be, what sort of being, again, a knowing subject must be and how he is related to his desires, whatever they may be, and so on. If the scientist takes for granted observation, the philosopher examines its meaning and possibility; if the former again finds the notion of evolution fruitful, the philosopher analyses it and points out that it can have no meaning without an unchanging background, that without a permanent unity of some sort changes would be unrelated and bewilder us like a perpetual Jack-in-the-Box. What, then, the theologian has first to do is to show that change, contingency, the imperfect, the relative, imply something absolute, and he concentrates his attention on what this absolute must be.

This procedure is clearly different from that of science, and roughly it can be described as deductive. It consists in examining what is supposedly ultimate, criticising this by means of the first principles of reason, which are in their turn subjected to an analysis, and so establishing what must be and what follows from the admission of these ultimates. The subject matter of philosophy is therefore one which of

its nature remains constant, and it may be said to cover that body of experience which is at the same time the most profound and the most common, that great human heritage which draws together into one family people from all times and from all the ends of the earth. It is to be found recorded in the Greek anthology, in the tombs of Mycenæ and the papyri of Egypt, as in Shakespeare and the modern novel—the love of a mother for her child and a child for its toys, the melancholy over the passing of what is fair, the respect for justice which drove Antigone to her fate, the longing felt by a Socrates for perfection, the warp and woof of life, the mystery of the self and its destiny, and God. Reflection on this commonwealth provides the philosopher with his material, and it was as possible for a wise man of the Egyptian dynasties, or Periclean Athens, to arrive at the truth about most of these matters as it is for a thinker of the twentieth century.

It would seem to follow from this that theology does not advance in the same way as science. Certainly it differs from science, and the complaint of Kant against it that it is stationary is really its glory. There must be at least one form of knowledge which escapes relativity if we are to have any standards at all and avoid complete scepticism. It is nevertheless more accurate to say that it does advance, though in a way different from that of science. Theologians sometimes use the word development to describe this, and two considerations will show what is meant. A child has some distinctions in its mind between the pleasant and the hurtful, between good and bad; it is taught proverbs and maxims and it clothes invisible beings in fanciful and sensible garb. In time it comes to realise what has been so far notional, to grasp vividly, for instance, such a saying as 'that it is sweet and fair to die for one's country,' and to discard the pictorial when meditating on spiritual realities. There is here a growth; meanings are realised and new relations understood. Now what happens to the child happens, too, in the advance of culture; the habit of imagination gives way to philosophy; the interest in external nature, in other men and women, in new worlds to conquer, as seen in the first vigour of Athens

or Elizabethan England, in the beginnings of novel writing, is succeeded by a new taste for which the self is the subject and the psychological novel the ideal. This seeing of what is permanent in new situations causes an advance in knowledge different from that in science. The second consideration bears less on theology than on other branches of philosophy. It is this, that though philosophy, as I have explained, has its own domain, the boundaries between it and science are not always clear cut. This is well seen in psychology; the problems of perception, of consciousness, of freewill, of the self, of the relation of the mind and body can be rightly claimed, I think, to be philosophic, and therefore as open to a right explanation from a Plato as from a Bergson, but, in fact, a modern writer ought to be better off because he knows far more about physiology and biology and so can avoid the temptations which beset the earlier philosophers to generalise beyond their premises and take over assumptions which subsequent science would show to be unjustifiable.

The theologian, taking the data of human experience, seeks to show a rational foundation for it and formulate what is confused in clear conceptions; and he also holds that the proper way to do this is to launch out on to the sea of reality with confidence in the power of the intellect to apprehend something of the ultimate nature of that real. The majority of philosophers have followed this route, Plato, Aristotle, Aquinas, Descartes, Leibniz and others, though since the time of Kant it has been abandoned by many. Kant's position precluded him from using arguments resting on the real as it is in itself and he criticised the old proofs as unsound because they contained as an implicit premiss the old ontological argument. His point comes to this: the cosmological argument relies on two premisses; 'being which is contingent or conditioned involves the existence of being which is necessary or unconditioned' and 'necessary being is supreme perfection.' Now in the second premiss it is only because the notion of perfect being is thought to involve necessarily its own existence that the con-

clusion follows—and this assumption is illegitimate. This criticism would be valid if Kant's theory of the limitation of our knowledge were correct, but other philosophers and scientists who do not accept his account of knowledge have no right to quote his conclusions, unless they arrive at them by an independent argument. It is their assurance, I fear, which contains what Kant called "a perfect nest of dialectical assumptions," such as, for instance, that the category of causality belongs only to the world of phenomena and may even be discarded there, that an infinite series is possible and that therefore the argument to a first cause has no validity, that one cannot get out of experience more than is contained in it. None of these objections touches the classical arguments for the existence of God, for they ignore the claim of the orthodox theologians that metaphysics is possible. This claim is not just an assumption; it is the condition of knowing and implicit in all assertions of knowledge. If I can never say that a truth is so sure that no further knowledge of reality can contradict it, then I can be driven finally into complete scepticism, and that itself would involve one inexpugnable truth. Now if there is a single truth which it is impossible to contradict, it follows that I know something about reality which holds true in every domain of it, that I have broken down the barrier which appeared to restrict me to one category of being. There is no truth, therefore, in saying that out of finite experience I can get only finite reality, that the notion of cause is empirical and, as such, inapplicable to metaphysical conceptions. Of all that is and can be I know something and something sufficiently common to allow me to pass from one part of reality to another, from matter to spirit, from the sensible to the intelligible, from the contingent to the absolute. These various orders are not entirely disparate, as many, following Descartes, have maintained or implied; I can make statements which hold good for them both and for any possible order, even the divine, if it exist. It is a mistake, therefore, to say that we know only the material, the sensible, the phenomenal or only the spiritual, the concep-

tual, or that the two are totally alien the one from the other. It is also an unjustified assumption to say that what we call the real is limited to what we experience and at most conditioned and finite. In our very first judgment we transcend experience, for we say that something is such and such, and it may be that both from the point of view of the judgment and from the nature of the object asserted to be, we may be forced to affirm also some existent, absolute subject or being. And this is precisely what the theologian does affirm when he says that existent, contingent being implies an absolute being or source and that every act of judgment, being in its own way absolute and yet progressive, can be explained only as a function of some absolute or in virtue of it.

All who admit the possibility of metaphysics—and the alternative is a self-destructive scepticism—will be bound to agree with what has just been said. It belongs to the prolegomena of a sound theology. What we have now to determine is the nature of this absolute or whole, for the preliminary remarks just made are at a first glance compatible with the views of a Spinoza, a Hegel or an Aquinas, with monism or monotheism. The arguments used to prove it go a certain distance to show what its nature must be, the arguments, namely, from effects and from contingency, from dependent essence and dependent existence, and they can be supplemented by evidence from design, from conscience and the unsatisfied urge of our nature to an effortless beholding of complete truth and the possession of what is infinitely desirable. The arguments, I say, can carry us a certain distance. If a distinction in the real order is required between what is absolute and what is contingent, between the dependent and the self-sufficient, then it is enough to show that what is perishable and finite is not mere appearance, for a solution on the lines of pantheism or monism to be ruled out. The perfect and unchanging cannot be composed of what is limited and changeable, and I might add that the expression, Reality as a Whole, is even more misleading than the word Nature. There must be some kind of meaning in the expression, and some kind of unity which allows

us to call anything whatsoever real, but this unity must be compatible with real differences and substantial differences. The relation of a human being to nature is different from that of a tail to the dog to which it belongs; we cannot class together under one identical name such variously assorted objects as thoughts, trees, penguins, cocktails, unicorns and persons. If we take persons, for example, we imply a certain kind of nature, privacy within that nature and a degree of independence and unshared responsibility. What kind of relation can they have to that which has been proved to exist, namely, a real object or subject which is completely and supremely real? It is manifestly impossible to work out in a few lines the answer to this difficult question, and so I must be content with just stating dogmatically the conclusion that since the nature of human persons, though perfect in its kind, is essentially limited and their existence finite, they must be dependent in these two regards on a being which in its turn, being complete and absolute, must be transcendent, sovereign and personal.

To call this supreme reality personal will seem to many a step quite unjustified by the argument just given. Even those who are ready to admit a metaphysical discussion of the kind I have sketched make a sharp distinction between the god of philosophy and the God men worship in religion. Philosophy, they say, may serve to prove the existence of some vague, abstract, absolute or necessary being, but this is little more than a confession that something must exist, which for the sake of a word may be called divine, though its nature be unknown. Religious experience cannot be content with such a dark mystery and overcomes the difficulty at a cost; it takes the best that we can think in the way of human ideals and so clothes God with personal attributes. He becomes majestic, wise, just, loving and lovable. Is this justifiable? Many would distinguish in their reply between the certainty of philosophical truth and the certainty needed for religion. The former is absent from this procedure, but religious experience does justify us in regarding God as personal and loving. If we look at history we find

that mankind has chosen one of two ways in its theology; either, like the Hindus, to renounce all description of God and in that renunciation find peace, or make up a 'myth' as worthy of him as possible. The West has followed the latter way, creating God after its own image, and experience has shown that it must contain some truth, no matter how anthropomorphic that truth be.

Now in this explanation the necessity of anthropomorphism is taken for granted. If, as I believe is possible, human thinking can escape this weakness, theology will rest on far surer foundations. No doubt the habit of humanising God has been very prevalent in religion, but that does not prove that it is necessary; and if what I have said of knowledge in a former paragraph be true, the means to overcome the habit are at our disposal. Human knowledge has two characteristics, that it is true and that it is limited. As true, it encompasses the whole realm of the real; as imperfect, it is suited to focus on only one province of it, the province of the sensible which can be measured. To put this in another way. If we suppose that an animal, such as a fox, is without reason, then the acquaintance which it has with external objects will be limited by its organism and animal faculties, and it will interpret all by its own experience and have no interest in things as they are in themselves. That is why an animal has no absolute standards in conduct, is indifferent to beauty and humour and knows nothing of truth. As Xenophanes of Colophon said, " a horse would call the gods a horse, an ox, a god ox-shaped." On the other hand, the differentiating mark of man is that he can know objects, not in terms of himself, but as they are in themselves, and though he finds this very difficult, by dint of reasoning and induction and the very power of the mind itself to criticise itself, he can succeed to some extent.

To see how this can be done let me recall one or two observations already made. The significance of our conceptions goes beyond what they can be said to represent. For instance, some of the recent conceptions of the universe are quite unimaginable, and we have always to be careful of con-

fusing what we may be bound to think about space or time with our fancy or imagination of them. Again, while we may be convinced that plants and animals have life, and that animals have a sensitiveness and awareness akin to our own, the differences are so striking as to forbid us to identify their experience with our own. A dog, if it could give the subject thought, would be wise in surmising that some of its master's behaviour showed anger, and wiser still if it guessed that the anger differed in many respects from its own. Now this principle of comparison and judgment can be applied to beings who are as much above us as animals are below us, and it is applicable even to God. If we find in ourselves or other things or persons any characteristic which in its pure condition is without flaw, we can attribute it to God, keeping in mind at the same time the proportion which must be observed between it as embodied in a finite object and in the divine being. By this means we are enabled to escape the Scylla and Charybdis of Hindu negation and anthropomorphism. Our thoughts, so to speak, circle round God and are not lost in the empty air, but before they can be said to be true of Him they have to be divested of the human livery with which we clothed them. If we ask can God be spatial or in time, developing or stationary, harsh and revengeful, forgetful or reflective, we can answer straightway in the negative, for all these characteristics imply by their very nature imperfection of some sort. If, on the other hand, we ask can God be just and loving, wise and personal, we must reflect on these qualities to see if they contain within their meaning any flaw. Wisdom, for instance, may well be perfect, for it means that to the possessor of it there is nothing hidden, that he can enjoy in the most intimate way conceivable all that is and all that can be desirable. That such a form of knowledge is possible we have no reason to doubt, though it is far different from our own. We have no acquaintance with it, and consequently when we attribute it to God we have to free the word wisdom from all the limitations we impose upon it. Like the dog in its meditation on anger, we attribute rightly the virtue of wisdom to

God, and so make a correct statement about His nature, while at the same time we refrain carefully from calling our wisdom God's.

This is the method whereby we elaborate a theology, and analyse with what truth and in what sense we can speak of God as cause and end, as transcendent and immanent, and by means of it we can bridge the gulf which separates the necessary being of philosophy from the God of religious experience. Thus both parties are mutually benefited, for theology is relieved of its abstractions and religious experience is rinsed by cold thinking. It must be confessed, however, that even so our knowledge of God and His ways remains very dark. The highest religious experiences are the reward of the few and they cannot always be communicated, and our thought about God, while, as I have explained, it can be true and informative, remains nevertheless oblique and fringed with mystery. Nothing else, of course, could be expected; indeed, if a writer were to make God easy of access and neighbourly, such familiarity would be almost a certain sign that he had lost sight of the true nature of divinity. This is the element of truth in the old saying that no one could see God and live.

And with this I may end, as I have contented myself with trying to describe what human thought and human experience left to itself can do to make a science of God. There is another theology which claims to rest not on what man can think of God, but on what God has deigned to say of Himself to man, and this is the specifically Christian theology. Though it claims to be in accord with reason, its first principle and ground are not reason but divine authority and revelation, and therefore it would need a new chapter to describe its method and subject-matter. Nevertheless, it can be invoked to throw light on the certain and tentative results of the theology of which I have been treating. This latter is bound by its very nature to leave much unsaid, to record far-off facts, leaving their relation in a luminous mist. It is the noblest of all studies and at the same time the most humiliating; it keeps itself straight by reliance on the most

fundamental principles of human thought and by discovering a means to apply what is best in human experience to God without error, due regard having been paid to the relativity in our ideals. But apart from the difficulty of keeping one's head on the soaring pinnacles of such thought, it is humiliating to realise the imperfection of it. There may seem to be proof, as Sir A. Fleming has said, "that the physical Universe is not in itself eternally enduring," that it is "not, therefore, self-produced or self-maintaining, but the result of a Creative power, and requires a continually operative Directive Agency. There are unquestionably in the physical Universe things that stimulate our appreciation of order, beauty, adaptation, numerical relations, and purpose in our minds—we who are thinking, feeling persons—and hence the qualities which excite these psychic reactions must have been bestowed on the Universe by a Sentient Intelligence at least as personal as ourselves." We may agree with Dr. Whitehead that there must be a God as a source of limitation and determination in nature, "the one systematic complete fact, which is the antecedent ground conditioning every creative act." We may be sure that the world, whether it be supposed to be eternal or temporal, is dependent on something else for its existence and continuity, that its meaning has not been imposed on it by us, that the labours of science go only to make these truths more manifest. Nevertheless, when all has been said and thought, we see only the shadow of God's nature and know only the rumours of His presence. The last word of unaided human thought on the relation of God to the Universe, the problem of predestination and freewill, the meaning of evil and the final destiny of man, is such that it raises as many questions as it answers, and there is no unlocking of the many seals of the divine volume unless God should deign of his own accord to make himself known by Revelation.

CHEMISTRY OF TODAY

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THE older text-books of chemistry often began with a definition of the science—"Chemistry is the study of the composition of matter," or some such sentence. But a science defined is a science dead, a moored hulk; and chemistry is emphatically not that. For a writer to attempt to define it now would argue himself either inexperienced or fossilized; and it seems that the only way in which a broad view of the science may be gained is to glance at the main themes that actually invite practical and personal study by men who are hailed as chemists. It is easier to say who is a chemist than to say what chemistry is; for it is a subject "whose margin fades forever and forever as we move," and it has many margins.

Look, for example at the "Annual Reports of the Progress of Chemistry" which the Chemical Society has issued for the last quarter-century; and notice the titles of the various surveys in any one year: General and Physical Chemistry; Inorganic Chemistry; Organic Chemistry—Aliphatic division, Homocyclic division, Heterocyclic division; Analytical Chemistry; Biochemistry; Crystallography; Colloid Chemistry; and a special report on the Structure of Simple Molecules. Geochemistry; Radioactivity and Sub-atomic phenomena; these are two other main headings which recur almost every year. Here is variety enough; and even so, almost every separate reporter pleads that he can deal only with a few of the advances that the year has brought forth in his own branch of the subject. It may also be noticed that the materials have been drawn from some 200 weekly or monthly research-periodicals, of which, though most are

specifically entitled "chemical," many lap over borderlands into sister-sciences.

It would seem at first sight that in chemistry the day of the 'Forty-niner' is over; that we have passed the simple alluvial stage of "placer-mining" for our chemical gold. It is perfectly true that most chemists hew and drill at the working faces of galleries which their predecessors had driven and opened up. Nevertheless, we still have with us—and shall have—the pioneer prospectors who seek out fresh deposits and, when they find them, inaugurate a "rush"; which itself will later steady down into more hum-drum deep-working in much hard rock, or even into the raking over of old waste-heaps for the sake of good gold still unwon.

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Suppose that we first examine generally the technique of chemical investigators, thereafter asking what it is for. Broadly speaking, chemical technique is of two kinds: qualitative and quantitative. The qualitative is what answers, more or less, to the naïve lay idea that "experimenting is puttings things into test-tubes and seeing what they do." It is the comparison of substance with substance: the recognition of materials, and of the fresh materials which they yield when intelligently intermixed, or when submitted to such agencies as heat, electricity, light. Quantitative chemistry, on the other hand, applies measurement to all such substances and to all such reactions. Its practitioners wish to know "How much?" before they can answer "What?" and "How?"

The coexistence of these two forms of technique, though it is not peculiar to chemistry, is especially characteristic of it. It should not be thought that, because quantitative study follows historically after qualitative, it is intrinsically the superior method. Each is a salutary and necessary check upon the other, each buttresses the other and reveals new fields of exploration for both; and neither can go very far in safety without the other's support. Measurements, in the

last resort, stand or fall by qualitative tests of identity. We might measure two triangles and find them equal, but it is their superposition without visible overlap which convinces us that the measurements were right; so, likewise, chemical judgments ultimately turn upon samenesses or unlikenesses, put to qualitative proving *ad libitum*. Without, however, straying into the philosophy of measurements, we should understand plainly that the qualitative, non-numerical aspect of chemistry remains an integral part of the science. Herein it differs, I think, from physics, which demands measurability in all that it handles. Physics did not and could not begin to take cognizance of chemical discoveries until these had been developed quantitatively by "physical chemists," who had themselves conjoined the functions of the physical measurer with those of the chemical "experimenter." And, conversely, the same intermediaries are constantly introducing their qualitative brethren to the discoveries of physics.

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We may select, from among the larger chemical advances of recent times, one which exercises especial dominance today. This is—to put it succinctly—the electrical character of the chemical atom: not solely as shown in a scrutiny of that atom's inward parts, but as evinced in the external properties of the atom and of groups of atoms. There are, in chemistry, very few old facts, and hardly any of the newer discoveries, of which the current explanations do not invoke electrical agencies. In this essay we need not engage in much historical retrospection; but it is well to recognize that the assumption of an electrical nature in atoms to explain their chemistry was being made long before anything definite was known about the internal architecture of an atom. We forgot, or had laid aside, the century-old idea of Berzelius that an atom or a molecule could be a "dipole" —that is, could have an electropositive head and an electronegative tail; but now, in another form, this is the essence of much of the foremost chemistry of today.

Looking back, we can see that inter-atomic action and molecular structure were studied from two points of view, at first very different and even opposed, but now brought very near together. Organic chemistry since 1874 utilized the idiosyncrasies of the carbon atom to study valency—the direction and the tenacity of the force linking atom with atom. If, in the course of this, organic chemists incidentally engendered new industries such as the manufacture of synthetic dyes; if they brought to light the nature of many natural drugs, and enabled these to be made for use and many new medicinal compounds to be invented; all this, part of the great economic contribution of chemistry to the world, while it is an earnest of the power of accurate research, is really a by-product of it. Scientifically, the main issue of the multitudinous studies which arose from the work of Pasteur, and later van't Hoff and Le Bel, and which included the long labours of such men as Wislicenus, Baeyer, W. H. Perkin, Jun., and their innumerable disciples, may be surveyed (very inadequately) when taken in conjunction with the major issue of the other branch of chemistry. Physical chemistry, with Faraday to match Pasteur, really appeared in 1886, with van't Hoff again as founder of it, coupled with Arrhenius in Sweden, and with Ostwald in Germany as their prophet. Their ionic theory for many years—almost a generation—interested organic chemists even less than organic chemistry interested physical chemists: and indeed, there are even now persons in one or other of these two folds who inherit the prejudices of those times.

In broad outline, the story is this. Pure chemical compounds can be roughly divided, by their behaviour, into two sorts. Those of one sort are marked by great quickness in their mutual reactions; the component atoms of two different molecules can change one partnership for another with no detectable delay, as soon as they are brought together in some suitable medium (usually water). In this class of compounds are acids, alkalis, salts; that is, more particularly, inorganic compounds. On the other hand, the substances of the second sort act upon one another much

more leisurely. Water, which so often serves as a dissolvent medium for the members of the former class, is less commonly of avail here, except in the natural laboratories of living organisms; but in any case the chemical interactions concerned are sluggish. The greater number of compounds in this class are organic compounds—compounds of carbon, with other elements such as hydrogen, oxygen, nitrogen, sulphur, chlorine; and they are usually complex, their molecules being composed of strings or circlets of carbon atoms, with the other atoms attached. But the distinction between these two great classes is not simply dependent upon the presence or absence of particular kinds of elementary atoms in the molecules. For almost any of the ninety elements can form part of a compound of either class. Clearly, then, the distinction lies rather in the ways in which the atoms composing a molecule, whatever their kind, are tied together; there must be loose linkages in the one class of molecule, tight linkages in the other.

The ionic theory started from experiments which show that the instantly-acting compounds are made of molecules which *spontaneously* split into smaller parts ("radicles"); and further, that these separate radicles, which are either atoms or small groups of atoms, are electrically charged, some positively and some negatively. These charged radicles are the "ions." On the other hand, the characteristically sluggish molecules of the other sort, with which organic chemistry largely deals, do not split up into ions. Their atoms preserve their pattern through a series of chemical vicissitudes, and are evidently more tightly bound together.

An early difficulty was that for a salt or acid or alkali to dissociate into electrified ions, there seemed to be required the addition of water, or else some other suitable liquid. Not all liquids would do this to the compound; but on the other hand, merely melting the pure substance by itself would suffice. In recent years this difficulty has been met by the discovery (partly due to work with X-rays) that a compound of this class is *always* ionized, no matter whether it is a pure crystal or has been dissolved in a liquid or has been

melted. The solid crystal is held together by the reciprocal attractions of the oppositely charged ions; and what the act of dissolution in water does is to enable the ions, already there, to float apart, helped by each ion's becoming attached to water molecules that act, as it were, as buffers between them.

So we arrive at the view that the force linking the component parts of a molecule of the highly reactive type is electrostatic: the same that makes a scrap of paper cling to a rubbed fountain pen, or hair crackle with a comb. It is a force which is easy to mitigate, so that the ions are loosened and can play "general post."

Yet consider another set of facts. Loose as ionic (or, to give them the better name, "polar") compounds are, nevertheless their crystals are far harder to melt down by heat than those of the other, the non-polar compounds. We must clearly distinguish between two tenacities; the electrical tenacity of the huge aggregate of ions, + and −, which is a crystal of a polar compound; and the chemical tenacity of the small aggregate of neutral atoms which is the molecule of a non-polar compound. An electrically neutral molecule, the molecule of a non-polar compound, exercises little force on another of like kind, and so a packed mass of them—the non-polar crystal—is easily melted by heat.

It may now be seen that physical chemists were really studying inter-*ionic* linkage—the union and disunion of electrified atoms; while organic chemists were studying inter-*atomic* linkage—the union and disunion of electrically-neutral atoms. In this latter study, organic chemists made great strides, and learnt to map out the structure of the most complex non-polar molecules with uncanny certainty. They could assign directions in space to the chemical force linking one atom to another, and could show how, by merely changing the sequence of the atoms in a given chain or ring, the strengths of the various linkages are affected. They learnt what conjunctions of atoms and linkages will produce properties such as colour in a compound; and far too much else to hint at here. But they had not reached the point of

assigning to all these inter-atomic linkages any underlying cause, even to the limited extent that we have just seen a partial cause for the inter-ionic links of a polar-compound.

The origin of both kinds of linkage began to be clear after the discovery of electrons. Thirty-five years ago, J. J. Thomson detected and measured the electron in gases under electric discharge; and he showed that the electrical charge which it carries is of the quality arbitrarily called "negative," and in quantity is the same as is carried by a chemical ion. He also showed that electrons can be liberated from all sorts of substances—that is to say, they are constituents of every kind of atom.

Here was the first evidence of any structural complexity in the atom; and naturally, it was to this new sub-atomic unit that chemists afterwards turned their attention, when they began to seek an origin for their "valency-bonds" between atoms or between ions. From the first discovery of the intra-atomic electron it was clear, however, that it could not be the sole ingredient of an atom; for the electron is negatively charged, whereas the atom as a whole is not electrified, and it must therefore also contain some positively charged ingredient to make the complete organism neutral. Also the atom has weight, the electron hardly any. Radioactivity, in the hands of Rutherford, and of Soddy and Fajans, eventually gave the required information, and established in 1911 the "Rutherford model" of the atom: planetary, negative, weightless electrons encircling a central, positive, massive nucleus. Moseley's work with the Braggs X-ray spectrometer completed beautifully the correlation of this model with the chemist's atoms; this work finally awakened physicists to the virtues of the old-established chemical ordering of the elements, and it has also been of the greatest value to chemistry by "calling the roll" of the existing elements, and as a weapon for discovering some others for which gaps had had to be left in the Periodic Classification.

It was shortly after this that G. N. Lewis put forth his fertile hypothesis of electronic linkage between atoms, which has re-united organic and physical chemistry, and has un-

doubtedly given the whole science fresh impetus. This is not the place for detail; the barest outline alone need be recalled. On the one hand, Lewis, in agreement with Kossel and others, ascribed the formation of a polar link between two atoms to the transfer of constituent electrons from one atom to the other; one atom thus receives negative electricity, becoming a negative ion, while the other, losing negative electricity, is left as a positive ion. The two new entities then cling together by electrical attraction. Such a transfer could only occur, naturally, if each of the resulting ions has a more stable electronic structure than the original atoms had; and it was shown that in fact the number of electrons so transferred usually adjusts matters so as to leave each ion with what is independently known to be a naturally stable number of electrons. The criterion of stability was laid down by Ramsay's "Inert gases"—the six elements from Helium to Radium Emanation—in which a proof of a maximum of architectural stability is the fact that they refuse to enter into chemical unions, and are also of all elements the most difficult to ionize by other means than chemical. On the other hand, Lewis conceived non-polar linkage as a kind of pooling of the electrons belonging to two neutral atoms, neither of which could afford to transfer electrons wholly to the other without deprivation beyond the number required for its individual stability. More shortly, the two atoms share electrons, in pairs.

Between the two modes of atomic linkage—by electronic transfer or by electron-sharing—it is difficult to draw an absolute distinction, and indeed the meaning of "sharing" electrons was for some time left obscure. But the last few years have seen a further great advance, chiefly contributed by physicists and lately by mathematicians. Niels Bohr took up Rutherford's atom, and made a synthesis of two distinct fields of science. That vast generalization of experimental chemistry, the Periodic Classification of the elements, was one of these fields; the accumulated masses of numerical data in spectroscopy formed the other; and Max Planck's hypothesis of energy-quanta, applied to Ruther-

ford's atomic model, gave Bohr the plastic idea with which he sought to bind together physics and chemistry.

Bohr's quantum theory is, like every theory that is of any use, *ad hoc*; but "*hoc*" here is such a millionfold aggregate of knowledge that the ultimate validity, if not the provisional expression, of the hypothesis is taken as established. Experimentally it has forced chemists to recognize that their molecules and their individual atoms are internally adjustable, by the access or release of energy; they are studying the steps by which an atom can be raised from lifelessness to increasing degrees of excitation until it can attack other atoms, or even cross a threshold so as to become an ion. The detailed aims, and still more the methods, of such studies are far beyond the scope of this article. One may, however, refer to the great body of studies of catalytic action, organic and inorganic (which action, by the way, is the foundation of much of modern chemical industry); photochemical and thermochemical work; work on the magnetic properties of pure substances; the beautiful researches of the laboratories of physical chemistry at Hamburg, on molecular rays; and the more purely physical and astrophysical developments of spectroscopy initiated by Fowler.

It may be allowable to offer an idea of the atomic mechanism propounded by Bohr, by way of a rough analogy. In its relation to the outside world, an atom may be compared with a motor car with its engine, clutch, and gear-box. The engine may be running (the electron may be rotating in an orbit), but the car does no work upon the road (no energy passes between the atom and outside it) unless a gear is engaged and the clutch is in. Further, at a given engine-speed the car can be made to do more work on the road surface if a lower gear be engaged; less, if a higher.

There is some effect akin to this in the atom; an electron can work now with one "gear" engaged, now with another; and there is nothing but "neutral" between. Bohr discovered the "gear-box" and defined the gear-ratios, in the machine which is the atom. (Whether the gear-changing is worked by a driver or by automatic "pre-selection"

is dealt with by Professor Planck in another article in this volume, and I shall not follow this perilous analogy further.)

The most recent work along these lines has been highly mathematical, based upon the quantum wave-mechanics which was devised to account for discrepancies between Bohr's quantum theory and detailed refinements of experimental fact. In the hands of such men as Heitler and London, Pauling, Lennard-Jones, this is beginning to attempt the problem of what underlies the sharing or pooling of electrons which is the valency-linkage in most of the molecules of chemistry. But this work is in its infancy, however fast it is developing; and it has not yet succeeded in being as good a weapon of induction as the relatively simple hypotheses which are guiding the majority of chemists, both physical and organic.

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It would be misleading to the reader if no mention were made of the recent extraordinary progress in at least one branch of applied chemistry—namely, the increase of biochemical knowledge. The hunting-down of pure substances vital to the living organism is a task which requires the utmost skill of the organic chemist, and the use of reagents and practical devices of which he alone among chemists is master. The isolation of some of the vitamins from treated foodstuffs is the most recent example of the same powers that first isolated adrenalin and other pure hormones from the secretions of a bodily organ. But, as with adrenalin, the biochemist's attack on such problems does not end with the extraction of a pure (and often unstable) compound from highly complex tissues; having got his material and proved its biological properties with the help of physiologists, he at once embarks upon two further tasks. The first is to discover the atomic constitution of the molecule of the substance—not merely, of course, its composition, for that analysis is very simple—but the whole pattern and exact architecture of its atoms. This task may sometimes prove

very long and difficult, needing many chemists, working in different countries, to clear up piecemeal corner after corner of the molecule's constitution, by successive degradations of its structure, just as is the case with some of the natural alkaloids. If this problem can be settled, the next step is to build up the substance from simpler compounds which any laboratory contains. Such a synthesis, if successful, may perhaps settle some still unexplained part of the first problem—the constitution; in any case, it would open the way to a biochemical goal of the greatest human value—namely, the artificial manufacture of a vitamin or hormone—which could be administered so as to remedy bodily and nervous deficiencies of the population. This side of biochemistry (for it is only one part of that branch of applied chemistry) is still at an early stage, and much is to be hoped from it.

. . . . .

Let us try to sum up the purposes of chemists' work. The objective of a given research or a series of researches (such as may occupy an individual and his collaborators for many years) may be one of three kinds. One, which is peculiarly the motive of those whom we recognize as the leaders of chemical science, is the simple desire to obtain a mental *picture* of observable processes, in terms of ultimate units. In saying this, one must not necessarily be thought to exclude the behaviour of "wholes" or aggregates; if an aggregate comports itself as a unit in respect of the process under survey, the student of the process will not need at once to analyse the aggregate into detailed parts. But such an analysis will sooner or later have to be made, if only to learn how far the behaviour of the aggregate is merely a summation of the behaviour of its constituents. Holism, taken uncritically, would be a lazy acceptance without understanding. So the progress of a science like chemistry must take the analytical road; and that road has successfully led us to the expression of large-scale, visible processes of nature in terms of ever-smaller units; each class of unit—crystal, colloid particle, molecule, atom, ion, and perhaps some day proton and

electron too—being shown to owe its properties to the summation of those of something still more subtle, or simpler. The reintegration, the summation, is usually an even more difficult work to carry out than the prior analysis; and because of this, an onlooker has to be no less patient than the investigators, and to refrain from expecting prematurely wide integrations in processes which are still under dissection. At intervals through it all, it is healthy to remember Francis Bacon's words:

"For that school is so busied with the particles that it hardly attends to the structure; while the others are so lost in admiration of the structure that they do not penetrate to the simplicity of nature. These kinds of contemplation should therefore be alternated and taken by turns, so that the understanding may be rendered at once penetrating and comprehensive."

It will readily be believed that for the chief objective of chemistry—the attaining of pictures in the mind's eye—there are pressed into the service numbers of investigators to whom the real personal incentive is something much less—or at all events, different. Many of these do their valuable work chiefly for the pleasure they take in the experimental technique: as, for instance, in the clean carrying-through of a chain of chemical operations, with pure, definite, and known substances at one end of the chain, and pure, definite, and new substances at the other; or again, in a systematic and highly accurate course of numerical measurements, made with apparatus calling for ingenuity in design and pure skill and precision in use, which shall describe some material or process more strictly than before. But Art for Art's sake is to us not an adequate justification for such labours; such arts, seductive as they are to every practitioner, beautiful as they most certainly are to the trained eye, must be Art for Science's sake. That is, for the sake of the further scrutiny and reflection which extract, from the products of the art, the aforesaid mental pictures. The accumulation of data is, for chemists, only the means to a verifiable picture.

We have spoken of three objectives of chemical research;

what are the other two? That which has just been described may be called the typical objective of a pure science. The other two, in varying degrees, are applications of chemical science to other things. Of them, some are illustrated under the titles already quoted from the "Annual Reports," and by the biochemical example already given. They are applications of chemical science to other sciences, branches of learning. Needless to say, the services thus rendered to the sister-sciences are not by any means one-sided, and are repaid at least in full. And finally, the application of chemistry to manufactures need only be mentioned to be appreciated. Most industrial processes depend upon chemical change, and their longevity (often their very birth as well) depends upon their being accurately understood. No stress has been here laid upon this aspect of chemistry, although it redounds to the very great benefit of chemical science itself as well as of industry, and although it is this aspect that is most commonly hailed as the chief value of the science. But to say that the sanction for chemical research lies in its industrial applications is no more true than to say that the value of poetry is to be measured by the profits of its publishers and the employment which it gives to printers. The virtue of a great scientific research is the same as the virtue of a great poem; and its spirit is the same also.

. . . . .

It remains only to add, in fulfilment of the plan of the essays in this volume, a note on a still wider theme. If the aim of philosophy is to determine the nature of ultimate reality, then I do not see how a chemist—or, indeed, a practitioner of any of the natural sciences—can indulge in philosophy except when he chooses to abrogate the principle by which he governs all his working life. In saying this I do not imply that such a bifurcation may not be allowable to him; indeed, in as much as he is human, he may not be able to avoid it; but I do wish to emphasize a fundamental distinction between any science on the one hand and metaphysical philosophy on the other.

The sciences aim at improving our understanding of the nature of Nature; and they are succeeding. But the absolute principle upon which is based all scientific work that has ever fulfilled this aim is, that no man can safely trust his cogitation about Nature. "Cogito, ergo sum," certainly; but the facile "Cogito, ergo est" is denied by science as having proved misleading, and is replaced by the humbler "Tango, ergo est." Scientific scepticism, the very root of scientific method, is not an axiom, not an article of faith; it is simply the austere wisdom born of millennia of experience. This experience has taught us uncompromisingly that human speculation about Nature, however lucidly expressed, however palatable, will not stand the straightforward test of being used to control Nature, except on one condition. This condition is that speculation must reach out no farther than experiment and observation can follow it at once. Only by this modest restraint has it been possible for natural science to advance and to enlarge man's understanding of himself as a part of Creation. And the advance began only when men avowedly abandoned wide guessing for controlled guessing. "Hypotheses non fingo," said Newton—I guess not at ultimates.

THE TREND OF PHYSICS

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AT the present time all ideas are in a remarkable state of flux.

The necessary revision of thought has to deal, in the first place, with those simple, elementary and fundamental conceptions which underlie the whole structure of science, and, secondly, with that fascinating borderland where experiments and theory are combining to unlock the secrets of the unknown.

In the effort to arrive at the plain truth a man endeavours to eliminate his individuality and to ascertain the behaviour of Nature apart from his own standpoint and mentality. In this undertaking he is often deluded into a false sense of security.

As a necessary result of his upbringing in the realm of Nature, man has habits and ideas derived from his inherited characteristics, his environment, memory and the speeches and writings of his fellow-men. Illuminated by occasional flashes of genius he can produce something the existence of which was previously unknown.

For example, man has invented a method of sending, from an aerial, continuous radio, or wireless, waves. The possibility of this feat is inherent in Nature, which permits electromagnetic radiation with a stupendous scale of frequencies. Yet, so far as is known, continuous radio (wireless) waves of, let us say, 300 metres in length, and therefore a million cycles a second frequency, do not, in fact, exist in Nature unless they are man-made. So, too, it seems that man alone, for fairly obvious reasons, projects himself over the surface of the earth with the help of wheels.

For the most part the Universe is a mirror wherein each man sees his own image, a reflection of his universal experiences. His own image is stamped on all that he would pass as true coinage, however honest his endeavours may be to eliminate himself and to abstract from all his experiences a clear vision of the whole.

If he is a student of the physical world, he may test by experiment the theory of a common origin of phenomena, so that, as Bacon wrote: "He will receive, from what he sees passing on the earth, clear information concerning the nature of the celestial bodies, and, contrariwise from notions which he will discover in the heavens, will learn many particulars relating to the things below, which now lie concealed from us." This is an excellent forecast of the close and beneficial tie existing today between physics and astrophysics.

Faraday, crowned with the laurels of his victory in linking electricity with magnetism, electricity with chemistry, and optics with magnetism, pressed forward eagerly to combine electricity and gravitation. His experiments were not successful, yet he writes: "Here end my trials for the present, but they do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists."

This search for the simplification of a unified field which will include both gravitation and electricity has passed from laboratory experiment to the powerful mathematical analysis of such men as Einstein, Eddington and Weyl. Yet Faraday clearly foresaw a unity, now largely embodied in the established idea that the physical universe is a manifestation of energy in various forms, for he wrote:

"I have long held the opinion, almost amounting to a conviction, in common, I believe, with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent that they are convertible, as it were, into one another, and possess equivalents of power in their action. In modern

times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of their equivalent forces."

This transmutability of energy, without loss of quantity, was well established long after Faraday wrote the above passage, so that to some extent the unity after which Faraday was striving has been achieved, and today we find matter and radiation, in forms kinetic or potential, all embraced in a single scheme under the Conservation of Energy, although the varied characters and forms of energy with their attendant "fields" will constantly form an endless subject for both discussion and research.

It is not easy to summarize present ideas of the fundamental notions and conceptions of science. There appear to be, on the one hand, observation, experiment, experience, perception, all imperfect; on the other hand, thought, imagination, abstraction, reasoning, conception. From these imperfect parents arises a new offspring, a proposition, a conclusion, a principle, a theory, something which is sometimes very improperly called a Law of Nature, for the idea is in the mind of man. If this new theory is expressed in analytical or mathematical form it may be subjected to most exacting tests—namely, to co-ordinate the past events or to forecast the future. The new principle is frequently found to satisfy such keen tests. The reasoning which has followed from quite imperfect experiments is discovered to have a close fit with natural phenomena past, present and future. We conclude not only that our reasoning faculties are trustworthy, but that there is an orderly process or habit in Nature which permits us to assume that under similar circumstances similar results will probably recur, in spite of the fact that no two events can be identical, differing as they must needs do in time, or in place, or, more commonly, in both.

Thus Newton was greatly impressed by the experiments and laws of Galilei, by his own experiment on water in a rotating bucket suspended by a rope, and by the experiments on the collision between two elastic balls of unequal sizes suspended side by side with separate strings:

"Sir Christopher Wren, Dr. Wallis and Mr. Huygens, the greatest geometers of our times, did severally determine the rules of the congress and reflexion of hard bodies, and much about the same time communicated their discoveries to the Royal Society, exactly agreeing among themselves as to those rules." Newton repeated these experiments, making careful corrections for the resistance of the air. He found that "Action and Reaction were equal and opposite," so that the momentum (mass × velocity) lost by the one body was exactly gained by the other. On so slender a base of experiment was built the philosophy of the *Principia*, with its concise mathematical reasoning, and yet the entire scheme was successfully extended to the whole solar system, to planets, moons, comets and tides, satisfying the observation of Tycho Brahe and the orbital laws deduced therefrom by Kepler.

Truly we may repeat with Boole:

"The domain of reason is thus revealed to us as larger than that of imagination."

Electrical engineers are in general ingenious and somewhat matter-of-fact men who generate or separate and transmit electricity or "juice" with complete success, not greatly worried by Maxwell's equations or modern atomic physics. Curiously enough they use frequently in their calculations about alternating currents the imaginary, or impossible, square root of minus one, and the symbol employed (j), denoting $\sqrt{-1}$, disappears from their final results, which are, of course, in agreement with future experience.

A great hydro-electric scheme may be devised, the head and supply of water calculated, dams constructed, power-house, turbines and generators planned, made and installed, distribution lines and transformers erected, and when the power is "turned on" everything works according to plan. A gigantic experiment in applied mathematical-physics, which today, owing to familiarity, causes little surprise! Noting, then, these great achievements of mathematics, physics, chemistry and engineering, it is pertinent to inquire whether the same methods might not be extended successfully to other fields—biological, moral and spiritual. Whether some

abstractions may be made from past and present experience which will fit closely with future development.

In most cases the number and variety of variables leave small hope of any approach to mathematical treatment. Yet it is fair to state that all the greatest moral leaders, teachers and thinkers have indeed followed that very path of abstraction from experience towards great principles which are in harmony with universal truths, and where the whole revelation is far wider and deeper than are the initial data. So that the fountain certainly rises higher than the apparent source.

What is that source? The late Lord Rayleigh once inquired, supposing that he discovered a really new theorem previously unknown to man, whether that theorem had never existed in any mind before. "To me," he said, "that seems unthinkable!"

What is that source?

"Mathematical notation is not a mere mechanism for calculating numbers, but the supporting framework of the organic relation of man's mind to the as yet unknown of which religions are the outward expression" (Mary Everest Boole).

What is that source?

"The most exhausting of all our adventures is that journey down the long corridors of the mind to the last hall where belief is enthroned."

It is an interesting but rather futile speculation to inquire as to what would be our present or future state of knowledge if the earth were covered everywhere with so dense an envelope of cloud that no rift permitted even a passing glimpse of sun, moon, planets or stars; whether the changes of length of day and night in different seasons and various latitudes would have permitted philosophers to infer a light-giving sun; whether the spheroidal shape of the earth, the gyroscope, and the famous Foucault pendulum experiment would have jointly suggested the rotation of the earth! And, if so, with reference to what exterior and unknown body or bodies, or what imaginary system of axes? It is useless to inquire; and according to Silberstein the question would have no meaning,

though he might himself indeed have been one of many who would have indulged in some such speculation. The history of science does record many similar inferences, which enter, rightly or wrongly, into the more speculative domains of physical science, even down to the present day.

Every physicist believes and must believe that there is something "in being" from which "messages" arrive to him by sight, sound or feeling, either directly, as by the eye, or indirectly as by photograph, which messages he can sometimes arrange and interpret so as to obtain so-called "laws" of Nature.[1] These laws are made by man, but the possibility of making them is a common experience of most men, and are presumably in Nature herself. These "laws" may therefore in an indirect and improper sense be transferred from man to Nature. The "laws" are summarised by man from past experiences, and they can frequently be used to predict probable future events—*e.g.*, an eclipse. They must never be regarded as fixed, certain, inevitable or immutable laws:

"Laws state what has been, and what may be expected to be; not what will always be, or what must be" (Tennant).

Hence Science cannot have dogmas or creeds, but only expectations of the future founded on the past; but there is an extraordinary weight of evidence of the permanence of the predictability of Nature, which increased knowledge intensifies. Hence, the man of Science is justified in combating superstitions founded on insufficient evidence or irrational thought, but he can never hope to fight successfully those experiences which are not the common property of a large number of experienced observers. Hence the troubles relative to divining-rods, telepathy, ectoplasm, second sight, magic, miracles and mediums generally. The proof of fraud in one càse cannot involve the proof of fraud in all cases. Here psychology is so mixed with physics that the pure physicist is like a little child before a skilful conjuror, and it is a law

[1] In spite of McTaggart, "The existence of matter is a bare possibility to which it would be foolish to attach the least importance." And of Ward, "As to ontal Nature we know nothing and can predict nothing, save with futility."

of conjurors that any required number of white rabbits can be extracted from a top-hat. On the other hand, there is a mass of evidence that rabbits do not normally enter the world in that manner.

In Physics, Nature is quite the gentleman and always plays the game. Whether white light passes through a glass prism or breaks up in raindrops to form a rainbow, the order of the colours is maintained and can be well "explained" by the simple laws of refraction in glass or water respectively. The next step is the "explanation" of the dispersion of light by the medium in terms of molecules, and this is referred to the scattering of light by electrons and protons either on classical or wave-mechanical principles. A further step has to deal with the constitution of electrons and their reaction with the so-called electrical "field." It is obvious that the chain of explanations can never end, so that Physics is and must remain inexhaustible in content. To the ordinary man these successive steps seem more like a retreat from the field than an advance on the citadel. Such chains of inquiries, criticisms and explanations are, however, inevitable in every healthy stage of scientific endeavour.

The methods of science are founded on observation and experiments, guided by reason and wisdom, and justified by success. The ultimate, or "ontal" (things that *be*), is always evasive and can be but partially inferred at the best, for the same phenomena can often be accounted for by more than one speculative entity. "Hence Hamilton was led to maintain that we have no absolute or pure knowledge of anything, and no knowledge at all of the absolute or ontal"; but Tennant judiciously adds that "our knowledge is relevant to Reality, while its impurity is an irrelevancy." And again: "Our laws of Nature are in some measure laws as to our thinking, as well as laws to the ontal; that is partly why similarities exist between equations belonging to different departments of physics, in spite of profound differences between the phenomena of which they obtain, so that things, of their own behaviour, make their laws, and 'obey' them by making them with persistent regularity."

The bells in the belfry are moved by ropes, and presumably know nothing and obey nothing, nor do they comprehend the ringers at the other end of the ropes. The ringers in the lower floor of the tower may also be in ignorance of the nature of the bells and the mechanical contrivances for supporting and swinging them, and yet the ringers may produce excellent chimes. Indeed, many great composers and musicians have been completely ignorant of mechanics, acoustics, and all branches of physics. We are the ringers of bells, and we can never be sure of the nature of the unvisited belfry whence come the wonderful chimes. We seem, however, to possess the too often abused power of "pulling the ropes."

No future event is more than probable, although it must be admitted that a mixture of oxygen and hydrogen is exceedingly apt to lead to a dangerous explosion when the smallest electric spark is passed through any part of the gas. The practical and common-sense man would say that such an explosion is *certain*, but if the gases are sufficiently dry, if nearly all water-vapour is abstracted, an explosion will not occur. There must be a trace of water-vapour to act as catalyst[1] and to produce the catastrophe. So, too, the change of a switch at a railway, though but a few inches, may decide whether a train shall go to Moscow or to Rome, and a trifling experience in a man's career may project him towards Fascism, Bolshevism or any other of the growing class of -isms.

Some of the apparent uniformity of Nature is carried down to fundamental concepts. Thus W. E. Johnson claims that "every specimen of argon has the same atomic weight; this specimen has the atomic weight 39·9; therefore every specimen has the atomic weight 39·9." This reads well and looks

[1] *Catalyst,* a "loosener up," a very useful word to disguise our ignorance of the great influence of small causes in physics and chemistry. However, "catalytic substances are those which modify the rapidity of a definite chemical reaction without changing their own content of energy." So that "within the strict province of the law of energy there still remains room for the greatest variation in the temporal extent of the phenomenon." (W. Ostwald.)

well, but it need not be true! It has been shown by Aston, at the Cavendish Laboratory, that argon consists of a mixture of at least two kinds of argons, whose atomic weights are 40 and 36. These two types of argons are *isotopes*, and occupy the same place in the periodic table. Their outer constitutions are very similar because the satellite electrons are identical in number and alike in arrangement. Hence these isotopes are non-separable by chemical methods, but they may be separated with difficulty and in small quantities by physical methods, so that the above quotation, which looks safe enough, is not in fact dependable. The statement might, however, be revised to read: "Every specimen of argon has the same atomic *number* 18, because *every* atom of argon has atomic number 18." This change in viewpoint involves a great discovery, with a notable advance in knowledge and simplicity. Atomic weight, or mass, is mainly governed by the number of protons in the nucleus, while atomic number has to do with electric charge, or the excess of protons over electrons in the nucleus. Argon alone of the elements has atomic number 18, while some calcium and argon atoms each have atomic mass 40, and may, in that case, be "isobares," or different elements with equal atomic weights or mass.

It is noteworthy that physicists in all parts of the world taking any specimen of iron, and using any good spectroscope, agree with one another in the main as to the wavelength and frequency of the many thousands of lines in the iron spectrum. These lines are due to the "messages" from the iron atoms when disturbed in an arc or spark due to a current of electricity passing through a small gap between two pieces of iron. It is perhaps possible, but certainly difficult, to infer the mechanism of the oscillating electrons. It may well be that several different models or schemes or mathematical formulæ would account for the same messages. A good cuckoo clock may sometimes fool you into the belief that an early messenger of spring has arrived in the land! Any scheme will be acclaimed as satisfactory which will give a good account of the spectrum of iron, and also of other metals, such as tin, lead, mercury, silver and the like. The inquiry would

then be enlarged in order to ascertain whether the "explanation" can be extended to apply to other phenomena such as the valency bonds which link atoms together into molecules.

There can be no intellectual satisfaction if the physical chemist arrives at one model of the atom and the spectroscopist to a wholly different and inconsistent scheme. Such a state of affairs is not at all imaginary. Not long ago discussion was rife as to the rival merits of the Langmuir static atoms and the Bohr dynamic atoms. These both have served, or are serving, a useful function; they are some sort of approximations to the "real" atoms, all messages from which we strive to interpret correctly.

It is remarkable, and somewhat puzzling to physicists, why some philosophers and others appear to attach so much importance to those "messages" which are seen by the eye or heard by the ear. The "existence" of many stars, never actually seen, or likely to be seen, is inferred from photographic plates exposed in the field of a good telescope for a long period of time. These stars have as much claim to recognition as those seen directly by the eye. It is true that their position on the plates is usually determined by the eye, but with the help of a source of light, a photo-electric cell and an amplifier it would be quite possible to ring an electric bell so as to reveal the position of each star, both on the photographic plate and in the heavens; and in that case the messages from the invisible stars could be appreciated by the ears of men totally blind.

Seeing and hearing are specially and highly organised methods of feeling, and the old adage "Seeing is believing" should be changed to "Feeling is believing," and even that saying should be confined to belief in the feeling until other evidence is forthcoming.

In the above discussion nothing has been said of the transfer of the messages from eye, ear or surface of the body along the nerves to the suitable region of the brain. The importance of these transfers cannot be over-estimated, particularly because when in good health we are entirely unconscious of the whole process. We enter here into the domains of the physio-

logist and psychologist, each successive stage involving greater difficulties. It is scarcely possible to imagine that the transfer of a purely physical message of light of a given wavelength into the psychical appreciation of a given related colour can ever be approximately explained, whatever the character of the intermediate physiological processes might be.

There is a further point which is a puzzle to physicists, this time in the domain of biology—namely, the frequent use of the word "function." Certainly the function of the eye is to see, of the ear to hear, and of the heart to force rhythmically the blood supply through the arteries. These organs have been developed for a purpose; for what purpose is often obvious; by whose purpose is obscure.

No doubt the function of a galvanometer is to measure current and of a thermometer to indicate temperature; these instruments were constructed and calibrated by deliberate human design for concise purposes. Writers on physics, however, rarely, if ever, make use of the term "function" in the manner of the biologists. We have to conclude that the word "function" either indicates a purpose with a definite design or, excluding such assumptions, we may attempt an explanation on the basis of trial and error, with more or less prompt elimination of failures. In that case, what is the use, let us ask, of a half-evolved and imperfect semicircular canal with a view to guiding the equilibrium of a body?

It may be that "the sting of Darwinism rather lay in the suggestion that proximate and 'mechanical' causes were sufficient to produce the adaptation from which the teleology of the eighteenth century had argued to God" . . . so that "the discovery of organic evolution has caused the teleologist to shift his ground from special designs in the products to directivity in the process and plan in the primary collocations" (Tennant).

If that is so, then there may perhaps be a general Cosmic End, or Purpose as a whole, of which there is no certain evidence in the parts; unless the entire mechanistic plan is itself the indication of an omnipresent purpose. Certainly no account of the Universe is complete which does not give

adequate reasons for the highest qualities of man, and those for the present, and probably for all time, are definitely outside and beyond the range of any type of exact science.

Some may prefer to discard the whole preceding suggestion and regard Nature as the inevitable outcome of chance happenings, to advocate the evolution of man from inert matter through simple cells and a chain of creatures up to his present physical and mental development. We are thus asked to accept the most stupendous chance and the highest improbability, a miracle greater than any that has ever been conceived. A miracle that has not only occurred in the past, but moreover persists in occurring before our very eyes, here, now! Indeed, there may be no need to consider the remote changes, but let the case rest on the stages from conception to birth. Familiar happenings such as the hatching of chicks from eggs can be traced, step by step, and experiments involving modifications can be made, but that the whole proceedings in any way resemble the manufacture of a locomotive engine is palpably absurd and advocated by none. It is not difficult to trace the development of the foot from the "dawn horse" to the latest Derby winner, but none can guess the process forwards to the horse or horses of a million years hence. By careful breeding and selection it might be possible to reverse the process and to devolve, or revolve, to the five-toed horse. Yet this, too, would be an evolution, for that which happens with advance of time, whether we deem it good or bad, progress or regress, must inevitably be evolution.

There are, however, still a few who carry forward into all realms such conceptions of exactitude as are associated with solar systems, Ford cars, moving pictures and so forth, and their only insufficient plea is the pertinent question, "What else can we do?" No series of successful applications of this method can ever succeed in proving that the mechanistic theory in any degree represents the entire situation.

We have climbed to our present state of knowledge on the backs of a few giants! Notable is the early contribution on the magnet by Gilbert, Physician to Queen Elizabeth, a defi-

nite scientific achievement predating the work of Galilei, Kepler and Descartes. The reference of Nature to experiment and reason, as opposed to speculation and authority, was the work of Galilei, while the full blaze of real physics burnt forth with Newton, who revealed the calculable orderliness of the solar system, to which the most highly organised railway system can never hope to attain. The younger science of Electricity began its brilliant career early in the eighteenth century with Galvani, Volta, Oersted and Ampère, but the experimental researches of Faraday and the mathematical genius of Maxwell have enabled electricity to outstrip and even sometimes to supplant the older science of dynamics. Hertz was able to discover the wireless waves which Maxwell's equations inferred, while towards the other end of the great electromagnetic system Röntgen produced the short waves which are able to penetrate considerable thicknesses of all material bodies. Improved technique in obtaining high vacua had already enabled Crookes to discover cathode rays, which he surmised to be "matter in the fourth state," which J. J. Thomson proved to consist of swift-moving corpuscles, or electrons, now known not so much as matter in a new state, but rather as one of the main fundamental constituents of all the atoms of all the elements.[1]

Four years before the close of the nineteenth century H. Becquerel discovered the radioactive property of the atoms of the heaviest element, uranium. There followed in rapid succession the discovery of polonium and radium by Madame

[1] The pastime of atom building has developed new interest now that the fundamental building blocks have advanced in number to six.

Name.	*Charge.*	*Relative Mass.*
Electron	$-e$	1/1845
Positron	$+e$	1/1845 (?)
Proton	$+e$	1
Neutron	0	1
Deutron	$+e$	2
Alpha particle ...	$+2e$	4

The last two can be built from protons and neutrons however.

Curie, the theory of radioactive change by Rutherford and Soddy, and the unveiling of the periods and properties of more than forty different elements which spontaneously disintegrate and transmute according to a simple and rigorous law or rule. It is memorable that the Theory of Radioactive Change was deduced from experiments on only two substances, Thorium X and Uranium X, that it was developed in Rutherford's Bakerian Lecture, and that it has since been found to hold rigorously for *all* radioactive elements.

The twentieth century opened with the discovery by Planck of the atomicity of action and the quantum nature of radiation. Energy exchange between atoms takes place in bundles strictly proportional to the frequency of the electromagnetic waves. It is remarkable that investigation of the energy distribution in the spectrum of radiation from hot bodies, a statistical effect, revealed at the same time the values of Planck's constant, h, and of the electronic charge, e, within a small percentage of the best experimental values since obtained by a variety of other methods. It might perhaps be expected that these small values would be "smoothed out" in any experiments dealing with the great concourse of atoms, and it is significant that the facts are otherwise.

Philosophers sometimes complain that physicists are constantly changing their viewpoint. In the very forefront of discovery this is indeed true, and such fluidity of thought is a most desirable asset, to be envied by theologians, politicians, economists and others. Behind all these vanguards of thought there is a great body of solid and permanent achievement, among which Planck's work will ever hold a leading place.

Rutherford's experiments with thin metal foils bombarded by the alpha particles from radium definitely established the existence of a small central nucleus in every atom where the preponderating bulk of the mass of the atom was concentrated, so that it was proved that all matter was by no means continuous but "full of holes."

Moseley exposed a number of substances, consecutive in the periodic table of elements, to the action of Röntgen rays, and the characteristic radiations, after reflection from a

crystal surface, were dispersed so as to indicate the natural periods of the higher frequencies. It was possible to demonstrate that the atomic number could be definitely identified with the number of positive unitary charges of the nucleus.

Bohr linked the measured frequency of radiation from atoms with the orbital satellites round the Rutherfordian nucleus,[1] intimately connecting in numerical agreement the frequency, Planck's constant, Moseley's atomic number, and the electronic mass and charge. The dynamical assumptions could not be rationally upheld, but in the case of the simpler atoms the verifications were so conclusive that the achievement was Newtonian in splendour. There followed the ejection of protons from the lighter elements by bombardment with alpha particle, and the designed transmutation of elements when the alpha particle remained in the nucleus, and a proton was displaced, thereby producing a definite change both of atomic number and of atomic mass, by Rutherford, Blackett and others.

The recent discovery by Lord Rutherford and his co-workers, Dr. Cockcroft and Dr. Walton, is specially noteworthy. Occasionally a proton, urged to a high velocity with a few hundred kilovolts, enters into partnership with the nucleus of lithium with its seven protons and three electrons, and the combination apparently splits into two alpha particles, which on loss of velocity acquire electrons and become two helium atoms. Thus hydrogen and lithium in a sense physical, and not chemical, give rise to helium.

The Rutherford-Bohr theory of the atom has indeed stimulated research and has been extraordinarily fruitful in problems relating to the nucleus of atoms. Meanwhile the theory guided research students through successive stages in the unravelling of the tangled skein of the spectral lines of the various elements, but successive and increasing difficulties

[1] The quantum of radiant energy (Planck's constant multiplied by the frequency) from an atom is equal to the energy released by a definite change of " level " by the orbital electron. This generalization due to Bohr is quite fundamental, and is closely akin to Einstein's photoelectric relation.

arose until about 1925 it became apparent that the whole scheme was but an approximation to something far more subtle and exacting.

A new outburst of what might perhaps be called modernistic, or ultra-modern, physics sprang rapidly into being. It is too early to estimate the full potentiality or ultimate success of this great movement. It must suffice to indicate its character and scope. The principal actors in the new drama of modern physics are notably young men—Heisenberg, de Broglie, Dirac, Schrödinger—though the comparatively veteran Bohr has often been leader or pilot.

It was Heisenberg who first broke away from the now old quantum mechanics and, ignoring models and orbits, focussed his attention on a scheme of mathematics which would portray as accurately as possible the essentially observable and measurable results of spectroscopy. It must again be urged that the lines of a spectrum on a photographic plate indicate frequencies of vibration, originating presumably in the atom, and indicating some vibrational changes of an abrupt or oscillatory character, from which the nature of the atom may be inferred. Heisenberg concentrated his attention on these measured "messages" rather than on the constitution of the atom itself, which might have an indefinite number of possible mechanisms satisfying the data. Heisenberg, Born and others set forth in an array, or matrix, the set of all possible oscillations involving both frequency and amplitude, still using the fundamental principle that the radiation quantum is equal to the energy change of the electron in the atom. They then proceeded to deduce rules which would account for the amplitude and intensity. Definite calculations with reference to the spectra of hydrogen and helium showed a fruitful crop of verifications with the more fundamental views usually identified with electronic behaviour.

So long as the electron was regarded as merely a small spherical entity of the type of electricity designated most unfortunately as "negative," it could be stated that every electron was like every other electron, so that if two of them

exchanged places in an atom or molecule no experiment could possibly detect any resulting difference.

Spectroscopic analysis, however, indicates that there is a fundamental difference between electrons and that this could be accounted for by the conception of a spin. A rotating electrical charge resembles a current and gives rise to magnetism, so that one end of a spinning electron is a north pole, the other end a south pole. Two electrons in proximity, with their corresponding poles close together, would react with a repulsive force, but, if their opposite poles were near one another there would be an attraction. An electron has today so unlocalised a character that perhaps a quasi-spin would be a better term to indicate the phenomenon in question. Just as two pendulous bodies attached to a horizontal cord can swing to and fro either together or in opposition, so electrons in an atom can be arranged to be symmetric or antisymmetric, and whichever arrangement exists also persists. We can therefore ask with great wonderment why the "choice" was made in favour of the antisymmetric! To quote Darwin:[1]

"Our principle then suggests that it is natural to suppose that the world is either wholly symmetric or wholly antisymmetric, but it provides not the slightest hint of which. As far as we may judge, worlds would be quite possible of either kind, but here the Exclusion Principle steps in and gives a definite ruling. The world was created antisymmetric."

In terms of the hypothetical electrons of the atom the fundamental rules of the atomic game seem to be:

(1) The identity of an electron in any atom is fully secured by four whole or "quantum" numbers. (These numbers when multiplied by $h/2\pi$ are, or have the character of, angular momenta.)

(2) No two electrons in an atom ever have the same labels or four quantum numbers (Pauli's exclusion principle).

(3) An electron is never observable in exact position when

[1] *The New Conceptions of Matter*, C. G. Darwin (G. Bell and Sons), 1931.

its velocity is known; and a knowledge of its position forbids a knowledge of its exact velocity (Heisenberg's uncertainty principle). This veto appears not to be due to the stupidity of the observer, but to be an intrinsic limitation due to the fact that *h* (Planck's constant) designates a lower limit to the value of action, so that further subdivision, as in the case of the electronic charge, does not or cannot occur.

Some philosophers seem to imagine that physicists conjure up these rather mad ideas of their own free will out of their fertile imaginations. Not so! They are thrust upon them by the stern facts of Nature, and the ideas only seem strange because they are unfamiliar. "Nature will open to the right pass-word, but she has chosen it, not we" (Tennant).

Working on parallel lines, Dirac at Cambridge independently evolved a most powerful super-algebra to deal with the same problems. Einstein's praise and criticism may be quoted:

"The latest and most successful creation of theoretical physics—namely, Quantum Mechanics—is fundamentally different in its principles from the two programmes which we will briefly call Newton's and Maxwell's. For the quantities that appear in its laws make no claim to describe Physical Reality *itself*, but only the *probability* of the appearance of a particular physical reality on which our attention is fixed. Dirac, to whom, in my opinion, we owe the most logically perfect presentation of this theory, rightly points out that it appears, for example, to be by no means easy to give a theoretical description of a photon that shall contain within it the reasons that determine whether or not the photon will pass a polariser set obliquely to its path."

This last point is not, however, to ordinary mortals the main difficulty, for Dirac's faultless logic and cold symbolism leave many readers in extreme doubt as to the nature and properties of the subjects or objects under discussion. The blame for this should not, however, necessarily be assigned to Dirac!

In the above quotation Einstein uses the word "photon"

expressive of his own theory of photo-electricity—namely, that light travels as a quantum from one atom to another atom, notwithstanding the wave theory of light so indispensable to the well-established interference of light. This dual character of radiation, involving spreading waves from a source, and at the same time the collected energy of a bundle, involves a definite contradiction which has been accepted rather than explained!

The French physicist de Broglie had in the meanwhile blazed a new trail! Guided by the beacon lights of Hamilton's work on Stationary Action, he saw that the paths of particles and the paths of waves might and should, under suitable circumstances, be identical. This was the first step towards wave-mechanics. In tracing light through a system of lenses, as with a telescope, it is often sufficient to speak of rays of light passing along straight lines. So, too, it is possible to give a fair description of a rainbow by the refraction and reflection of rays of light in the raindrops; but when the primary bow is doubled or trebled it is clear that geometrical optics is not sufficient, and it is necessary to pass to physical optics and to employ a wave theory. De Broglie realised that electron particles were essentially too crude, and that small waves, or rather groups of waves (wave packets, as they are called), could wheel round the nucleus of the atom, thus forming standing waves with an integral number of nodes. This idea of de Broglie was quickly seized and greatly extended by Schrödinger, who obtained suitable equations eliminating the time factor, and arrived at results well supported by experimental evidence, indicating the probable rather than the necessary position of the shifting electrons. To the mathematician Mott's *Wave Mechanics* may be recommended, and to others a brave attempt at explanation has been made in C. G. Darwin's *New Conceptions of Matter*, of which it may be said that, from the nature of the subject, the success is necessarily partial, that the account could not have been a better one, and the wonder is that it could be done at all!

In the first place, it is natural to inquire, with respect to the

de Broglie waves, "What is the nature of the medium in which the waves occur?" It is safe to reply, "Certainly not the æther." In the case of light-waves, which appear to travel at 186,000 miles a second through a vacuum, the answer may perhaps be the æther, whatever that shadowy conception may or may not involve. In the case of the de Broglie waves, however, a velocity is involved which is greater than the velocity of light. This is sometimes spoken of as a phase-velocity, and the velocity of a group of such phase-waves is the observed and measured velocity of any particle. It is perhaps more correct to state that in the case of the de Broglie waves there is no medium at all, although the transformation equation of Einstein's special relativity theory clearly points to the existence of a velocity.[1] Indeed, Mott, writing on this matter, and referring to Schrödinger's wave equation, states:

"The wave function is just a convenient shorthand. The waves are not waves in any medium. There are no waves accompanying an electron, until we have observed the electron. Then we make use of the wave representation to embody the results of our observations. The wave equation tells us what may be deduced from our observations, about the future position and velocity of an electron."

This hardly suggests a final position to be occupied by physicists, but rather a *point d'appui* to be consolidated for a further advance. Rather it may be asked why physicists have permitted themselves to be manœuvred into a position so dangerous and vulnerable. The answer is twofold. In the first place, it became necessary to abandon the *definite* Bohr orbits for the electrons moving as satellites round the Ruther-

[1] The time and space transformation equation in question is—

$$T = \frac{t - \frac{vx}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

and here is indication of a velocity $u = \frac{c^2}{v}$ where v may be the velocity of a particle, which can be proved to be the group velocity of u.

ford nucleus of the atom. These orbits gave a valuable first approximation to the facts, but they could not stand the tests of experiments, so that some modifications, whether of Heisenberg, or de Broglie, or Schrödinger were essential. In the second place, the wonderful experiments of Davisson and Germer, and of G. P. Thomson, definitely proved that electrons had not merely the attributes of charged particles, because a narrow beam of electrons fired through exceedingly thin sheets of aluminium or gold foil gave interference patterns strongly resembling those due to Röntgen rays under somewhat similar conditions, but with this notable and fundamental difference, that the Röntgen rays and their patterns cannot be deflected by a magnet, while the electrons and their patterns can be readily shifted *en bloc* by a magnetic field from one position to another, indicating that photons have no electrical charge, while electrons have a "negative" charge, negative merely being a description of the type of charge and not a minus quantity. In fact, two definite conclusions are forced upon us. The photo-electric effect—that is, the ejection of electrons from atoms by light—indicates that a "particle" scheme is necessary as well as a "wave" scheme for light. The word "photon" is used to denote that which has this dual nature. On the other hand, the experiments just described show that an electron is not merely a charged particle, as formerly supposed, but it has also something of the nature of waves.[1] The universe seems to be built of particles that are wavicles and wavicles that are particles. The physicist has three[2] entities to play with—electrons, protons and photons—with their attendant "fields." The characters in the drama are somewhat difficult to control, as they are constantly changing their rôles from Mr. Hyde to Dr. Jekyll. Most of these remarkable properties have been established rather than explained, and it is impossible to guess whether

[1] The photon has energy equal to Planck's constant multiplied by the frequency, and the electron has a wave-length equal to Planck's constant divided by its momentum. A remarkably simple and well-established result.

[2] See, however, footnote p. 225.

an explanation may ever be forthcoming or whether we are at last driven to the "nature of things!"

For example, in the famous wave-equation which Schrödinger so effectively uses there is a characteristic function of that which waves, denoted by the Greek letter ψ (*psi*). What does this stand for? Jeans gives the answer:

"Most of the symbols used by the mathematical physicists today convey no physical picture to his mind; he can explain and predict the whole course of atomic structure in terms of the behaviour of a symbol—the ψ of Schrödinger's wave-mechanics—but he cannot tell us what ψ means in physics; and I for one doubt if he will ever be able to do so."

A most unsatisfactory state of affairs! Yet, as Mott states, as far as "atomic fields are concerned the predictions made by the wave-mechanics are in accordance with experiment, so far as is known at the present time." And again, to quote Darwin:

"It is one of the most unsatisfactory features of the enormous recent developments of science that they are so remote from all the ordinary things of life."

Thus, for example, if a beam of electrons is fired at two small holes, made close together through a screen, there will be an interference pattern of light and shade on the receiving photographic plate, placed behind the screen, and Darwin states: "The only possible way of explaining this is to say that each of the electrons knows all about both holes, or has gone through *both* holes at the same time, because only then could we get the cancelling effect characteristic of interference. This is the direct inference from our experiment, and there is no escape from it. It is so contrary to all our ordinary ideas about matter that it must be regarded as the greatest revolution that has happened in the whole of physical science."

If an electron has to be represented by a little packet or bundle of waves, we may well ask at what point in the bundle is the mass, and where and what is the negative electric charge? No suggestion has been made as to the nature or position of the electricity as apart from the mass, and the answer

seems to be, in this case and in all cases, that it is impossible to state where the electron is; all that can be said is that the most *probable* position of the electron is wherever the waves have the greatest amplitude, where the storm waves are highest, as it were. Indeed, intensity and probability seem to be reversible terms.

The wave-mechanics gives an explanation, and indeed the only explanation, of the remarkable properties of radioactive bodies. A uranium atom " spontaneously " breaks up on the average once in a thousand million years when an alpha particle escapes from its electrical captivity in the nucleus. On the other hand, a quick-change atom effects a similar ejection in about a millionth of a second. It appears that the alpha particle is also a wave group or wavicle, and while a real particle *never* could escape from its captivity in the nucleus, there is a probability of escape for the alpha wave-particle; this probability is indeed calculable, and there is a satisfactory relation, verifiable by experiment, between the velocity of the ejected alpha particle and the average time of imprisonment in the nucleus.

Far less satisfactory to a physicist, however pleasing to the mathematician, is the fact that for the description of even *two* electrons circling round outside the nucleus of an atom it is necessary to use *six* dimensions to obtain even the probability of their position. I can do no better than quote Darwin again:

"We have seen that many of the characters of an electron can be represented by regarding it as a wave-group moving about in space. It would be tempting then to suppose that, when there are two electrons, there are two wave-groups both moving about in space. But this will not do, since two wave-groups are simply a single more complicated wave-group, whereas two electrons are radically different from one. For the correct treatment of the waves of two electrons it is necessary to have two spaces, or in the language used by mathematicians, a space of six dimensions. Of course, there are not really six dimensions, but the mathematician finds it convenient to think and speak in that way. The best picture

we can make for ordinary use is something like this. We can make a diagrammatic representation of the wave of an electron by sketching a wave-group on a sheet of paper. It is true this is only in two dimensions, but it is comparatively easy for us to understand three dimensions when we have mastered two. The behaviour of two electrons is described, not by two wave-groups on the paper, but by having two sheets of paper each with one group on it. The second sheet overlies the first. As the motion goes on, each smudge moves about in its own sheet and no transfer from one to the other is allowed. Nevertheless, the ink of each group can, so to speak, see what the other one is doing, and experiences a force from it. Since there is repulsion between two electrons, we can say that the patches try to avoid one another. On the other hand, there is attraction between an electron and a proton, and so in that case the two patches tend to come together. This description of the behaviour of two particles applies in cases where they do not approach very closely to one another, but we are going to meet cases where things are not so simple, and where the six dimensions cannot be divided into a pair of threes. I am involved in the difficulty of having to explain ideas which are mathematically fairly easy in terms of the geometry of several dimensions, but which it is by no means easy to apprehend physically."

Enough has now been said to whet the appetite of the reader for more information. The Universe is far stranger than any of us foresaw. To avoid the metaphysics of "ideas not essentially observable" we have certainly run into a type of mathematical description which transcends physics in its essential mysticism. This new science is very new, only a few years old. It may be too beloved by the gods to survive, for "those the gods love die young." It may grow up and become extremely unlike its babyship. But in any case it stands already triumphant as a theory which stands all square with experimental facts.

After a great outburst of mathematical physics there has been a noteworthy return to high achievement in the laboratory, particularly in connection with cosmic radiation,

with the positron, the neutron, and such striking confirmation of the correctness of the general viewpoint on atomic structure as the production of two alpha particles from lithium (atomic mass 7) and a swift proton entering its nucleus. Further developments in this direction are eagerly expected, and in the meantime it is interesting to note that two great authorities, Einstein and de Sitter,[1] assure us that there is, at present, no certainty as to whether the radius of our three-dimensional universe is positive, zero or negative—that is, whether the general character of the large-scale geometry of the universe is elliptic, Euclidean or hyperbolic in type, so that the size of the universe may or may not be finite, although this problem may be capable of solution when there are more astronomical data available.

On the other hand, it seems to be well established that the distant nebulæ are receding from us and from one another at an amazing speed which increases in proportion with the distance, the velocity being, in fact, about 500 kilometres per second for every million parsecs, where a parsec is about two and a quarter light-years. This expansion, of the distances between nebulæ, is so rapid as to lower the time-scale of the universe as derived from other considerations; so that an oscillatory universe may be the correct surmise. In any case, the old view of a static universe with its "fixed stars" has given place to a more fascinating picture of a universe full of motion and dynamic complexity.

[1] *Proc. Nat. Acad. Sci. of U.S.A.*, 18, 3, pp. 213, 214 (March, 1932).

THE VICISSITUDES OF A HABITABLE GLOBE

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FOREWORD

WE inhabit a world which has had a marvellous surface history. Physical changes of great magnitude have again and again affected its surface structure; and on each occasion the changes have been much alike in character. The continents over great areas sink down into the ocean and the waters close over them. Air-breathing life —animal and vegetable—which for ages flourished over these areas has to perish. But the traditions of life are carried forwards by the life of the highlands.

In due course there is a great resurrection and the submerged land revisits the glimpses of the sun. Life migrating from the highlands once more spreads over the lowlands. So the history proceeds—Life prevailing through it all and never altogether forgetful of the past. For there is such a thing as organic memory; notwithstanding the fact that 'onwards and upwards' has been the attitude of the organism throughout.

The complexity of the Earth's surface history has only recently been deciphered. To this subject we have patiently to confine our attention in the first instance. The reader will note the steadily repetitional character of that history from age to age; and the actually sub-atomic nature of the forces which have supplied ultimately the creative energy; and built up the glorious mountains of the earth. He will gather that the same stately march of events must continue into a future inconceivably remote.

Again, the reader will note that the advance of life from its rudimentary forms to that of Man has proceeded along very different lines from those which directed the purely physical earth-history. Not that any occult forces have been involved, but that events are so regulated in the growth of the organism as enables it to evade the immediate consequences of a certain law of thermodynamics. Hence the final triumph of the organism and the existing abundance of life upon the Globe; and hence, too, we reasonably infer its existence in other worlds than ours.

The greatest accomplishment of Geological Science in recent times is the recognition of the fact that the surface history of the Earth is marked throughout by repeated invasions of the sea upon the land.

The reality of this record admits of no doubt. It is detected in the existence of ancient rocks of marine origin laid down far within the continental margins of today. Even in remote Archæan times vast depths of marine sediments were deposited far within the existing continental areas.

The great invasions of the continents by the waters of the oceans constitute, indeed, the leading events of the surface history of the Earth throughout all geological time. When signalised by the fossil remains of contemporary marine organisms they enable us to decipher a definite surface history as extending over some hundreds of millions of years. Thus we learn that geological history is by no means a monotonous ageing of the great continents. Far from it. An extraordinary sequence of events was repeated again and again. Events revealing no signs of decadence in the great forces to which they might be ascribed.

Some of the greater of these events are best referred to by the descriptive name which has been given to them by American Geologists: They were so *revolutionary* in character as to justify the nomenclature which terms them *Revolutions.*

Our knowledge of these Revolutions has been as much due to American Geologists as to European. Indeed, as regards the pioneer work, much of it stands to the credit of investigations carried out in the New World.

Little by little, as field work extended knowledge, it was forced upon the early geologists that the mountains themselves were mainly built out of marine sediments. Folded and piled-up beds of calcareous strata or arenaceous sediments were found to enter into the structure of the Western Mountains of North and South America; of the Alps of Central Europe; of the giants of the Himalayas, etc. That these beds were originally laid down in seas, now long vanished, was shown by their fossil content.

The Geologist was, in fact, presented with a record of unimpeachable veracity showing that in many cases where the mountains now are there formerly had prevailed wide inland seas or mediterraneans. Not very deep, perhaps, at any time; but communicating with the great permanent oceans of the Earth. Further, it was evident that in those epeiric seas there had progressed a steady accumulation of sediments shed from neighbouring highlands or secreted by organic life; the Earth's crust sinking locally under the ever-increasing load.

The sediments so derived were destined to form the future mountain ranges. For this to come about compressive stresses, arising after the long period of deposition, must have folded and uplifted the age-long accumulations of the ancient seas.

In order to arrive at some idea as to the areas of such former continental seas the folds of the existing mountains must be spread out. When this is done it is found that the continents as we know them today must have been for a considerable part covered by the epeiric seas.

The Historical Geologist divides geological time both according to superposition of strata and to organic evolution, as the accompanying table shows.[1]

[1] *The Surface History of the Earth*, by the present writer. Second edition. Oxford; at the Clarendon Press, 1930.

THE REVOLUTIONS AND DIVISIONS OF GEOLOGICAL TIME

Period.	*System.*	*Life.*	*Revolutions.*
	Recent	Dominance of Man.	
	Pleistocene	Palaeolithic Man.	
Tertiary (Kainozoic)	Pliocene	Advent of Man? Highest orders of mammals and plants.	
	Miocene	Continued advance towards recent forms—especially in molluscan and insect life.	Alpine.
	Oligocene	Continued advance towards recent forms.	
	Eocene	Dawn of recent forms of life. A marked advance over Cretaceous forms of life, especially in the Mammalia, is found in earliest Eocene. Early angiosperms.	
Secondary (Mesozoic)	Cretaceous	'Age of Reptiles' (both herbivorous and carnivorous) on land and in the sea; prophetic, in their various forms, of birds and mammals.	Laramide.
	Jurassic	Remarkable evolution of gastropods, cephalopods (ammonites), and bivalves, advent of Mammalia. Early cycads and conifers.	
	Triassic	Disappearance of Palaeozoic seed—ferns, Cordaitales, and Lepidodendraceae.	
Primary (Palaeozoic)	Permian	Evolution of air-breathing, vertebrate life continued. Advance in insect and plant life. Trilobites disappear.	Appalachian.
	Carboniferous	Great development of fern-like plants and of insect life. Ancestral amphibians on the land. Bivalve, crinoid, and coral marine life abundant.	
	Devonian	'Age of Fishes' (armoured and enamel-scaled types); first land floras; precursors of the amphibians; marine invertebrate life abundant, especially molluscs; brachiopods; corals. Decline of trilobites.	
	Silurian	Fishes rare at first; later abundant. Life mainly represented by corals, brachiopods, trilobites, crinoids, bryozoans and graptolites: the last become extinct in Silurian times.	Caledonian
	Ordovician	Advent of true corals and armoured fishes. Rise of shelled marine life (lamellibranchs and brachiopods); bryozoans and graptolites.	
	Cambrian	Dominance of trilobites; rise of cephalopods; primitive corals and sponges; brachiopods abundant; early lamellibranchs and crustaceans; land plants and land animals unknown. First known marine faunas.	
Proterozoic	Keweenawan Huronian	Worms; radiolaria; siliceous sponges.	Killarney.
	Timiskamian	Calcareous algae.	Algoman.
Archaean	Loganian	No trace of life.	Laurentian.

The most important events of all, as regards Earth-history, are the Revolutions. These are, by some writers, referred to as "Critical Periods" or "Eras."

The Revolutions are named generally after some great mountain development: as *Alpine, Appalachian,* etc. Geologists do not always select the same name, being, perhaps, in some cases impressed by the orogeny of one area more than of another area.

There is general consensus of judgment as to the periods of these great events of Earth-history. Perhaps the only exception is to be found in the case of the Laramide Revolution which is evident in America but not conspicuous in Eurasia.

Consider the existing fold-mountains of the Earth's surface. They are mainly alike in age all over the Globe and that age is a geologically recent one. The structural features of the Earth presented to us today are just such as would arise out of a great Revolution. What can have given rise to such structural features? A general shrinkage of the deeply-lying sub-continental and sub-oceanic materials of the Globe would account for them. Such a shrinkage as would result in the folding and crushing of those superficial materials which no longer have room to remain outspread upon its surface.

In the past there were similar world-wide epochs of shrinkage and mountain-building. The remains of the worn-out mountains are there still and tell us of former Revolutions.

Now if we seek to account for the repeated periods of mountain-building as arising upon the surface of a *steadily cooling* Globe, we have to assume that the surface materials possess such perfect rigidity as to resist the accumulated stresses of scores of millions of years of cooling and contraction before 'simultaneously' yielding to them all over the surface of the Globe.

This assumption is not in harmony with the physical properties of the surface materials of the Earth. All manner of rocks—sedimentary and igneous—yield steadily to long-continued stresses. The folding of the rocks visible in moun-

tain ranges is evidence of this fact. There is nothing in our observationally-acquired knowledge of mountain structure to support such views.

Plainly we must question the validity of the basal hypothesis that the Earth has all along been *steadily* losing heat.

The difficulty attending the assumption of a steadily cooling globe increases when it is recognised that the former prevalence of periods of great *tensile* stresses is abundantly evident in the surface rocks.

The effects of tensile stresses are for obvious reasons generally less conspicuous than those arising out of compressional stresses. But those who deal with mining operations, etc., are familiar with the effects of tensile forces as abundantly evident in the Earth's surface structure.

The most impressive testimony of the reality of epochs of tensile stress is to be found in the structural features of the African Continent. It is well recognised now that the chain of narrow seas extending north and south throughout the length of this great continent are the result of tensile forces rending the continental rocks to great depths.

Meridional rifting on a great scale is also conspicuous in South-Eastern Australia.[1]

Every fact we know today respecting this matter is opposed to the theory of a steadily cooling earth. It may be affirmed that the events of geological history from the remotest past are in discord with the history of a slowly cooling Earth. But they are in accord with a very different history. We have, in short, to recognise that there were periodic changes in the volume of the sub-surface materials of the Globe, such as would occasion alternate state of compression and tension of the surface materials—the compressive stresses resulting in the more monumental erection of the great mountain ranges.

Now such a succession of changes can be ascribed to one source only: the alternate fusion and regelation of the deep-

[1] Reed, *Geology of the British Empire*, p. 351.

lying sub-surface materials of the Globe. In such alternation the great phenomena of the Revolutions at once find explanation. This leads us to consider the evidence available respecting the nature of the Earth's sub-surface materials.

As leading up to this subject we have first to consider a structural surface feature of the Globe of comparatively recent discovery. This structural feature—known as 'Isostasy'—was first revealed some 75 years ago by a discovery made during certain survey operations carried out in Northern India.

In the course of these operations it was found that a plumb-line was deflected towards the Himalayan Ranges to a degree sufficient to introduce notable error into the verticality of the plumb-line.

Upon investigation (by Archdeacon Pratt) the curious conclusion was reached that the observed deflection was *less* than that to be expected from the calculated gravitational attraction of the great mountains.

Following upon this discovery Sir George Airy—then Astronomer Royal—suggested an explanation of the deficient attraction of the mountains: an explanation which has revolutionised our knowledge of the surface structure of the Earth. It amounts to the, at first sight, daring theory that the continents of the Earth are *floating* in a dense substratum which extends universally beneath the continents and oceans.

In short, the continents themselves and the mountains thereon float (like great icebergs in the ocean) in sub-continental materials sufficiently dense to carry them. We must picture the Himalayas, rising into the heavens, as supported from beneath by a great projection into the underlying denser materials. The 'error' in the deflection of the plumb-line is due to the fact that the attraction of the visible mountain ranges is off-set in part by the lesser attraction due to displacement of the heavier sub-stratum beneath by the lighter mountain-building materials.

This discovery has introduced entirely new views as to the surface structure of the Earth. The light continental crust

floats in a great substratum of heavier materials. The thickness of the continental layer is much greater than what we estimate either from height above sea-level or above the level of the ocean floor. This leads us to consider the nature of the materials in which the continents are floating: materials which must, of course, be denser than the continental materials.

The average density of the continents, judging from the rocks open to our investigation (mainly granites and similar highly siliceous rocks), cannot be far from 2·7 times that of water. If we assume that the average depth of the ocean defines the surface of the substratum—*i.e.*, 3·8 kilometres—and that the substratum in which the continents float is basaltic in nature (for which, as we shall presently see, there is very strong evidence), then, allowing for the buoyancy of the ocean water and taking the mean emergence of the continents over sea-level as 0·82 kilometres, we find that the total average depth of the continents is about 31 kilometres, of which 26 kilometres are submerged in the basaltic substratum. From other considerations, as we shall presently see, the normal thickness of the continents has been computed to be about 40 kilometres.

The evidence for the basaltic character of the substratum is very strong.

This rock has played a considerable part in the surface history of the Globe. It has been poured out on the surface of the continents many times since the commencement of geological time. Some of its flows date back to the earliest geological periods. Its density is about 3·0. It fuses at about 1,150° C., at atmospheric pressure, and a little above this temperature flows freely. It covers by far the greater part of the Earth's surface. There is evidence that the greater part if not the whole of the floor of the Pacific is composed of basalt. In the case of the Atlantic there is evidence of a layer of lighter materials (of continental character) covering a basaltic substratum. These facts have been inferred from seismic evidence.

Towards the end of Cretaceous times, or early in Eocene

times, basaltic outflows along the north-west boundaries of Peninsular India covered an area estimated to be not less than 500,000 square miles. Over 200,000 square miles to an average depth of one half a mile still remain. That is to say *not less* than 100,000 cubic miles were poured out.

At about the same time similar floods were poured out on the sea-floor of North-Western Europe, extending some 2,000 miles from Northern Ireland to Franz Josef Land and to an unknown distance westward over the Atlantic floor. This outflow possibly was continuous with plateau basalts poured out in Northern Russia.

In the Western States of North America the Colombia River basalts cover some 200,000 square miles. These flows reached their maximum in Miocene and Pleiocene times. Many other enormous floods occurred in the Front Ranges of the Rocky Mountains and along the Pacific coast. The great basaltic region of the Parana basin of South America shows floods of at least 300,000 square miles in extent. Great outflows are evident in Patagonia and in South-East and North-West Australia all of Tertiary age.

In the earliest times of Earth-history similar floods were poured out.

Now it is characteristic of these Plateau Basalts—so-called because of the form taken by the flows—that all over the Earth they are strikingly alike in chemical composition.

In short, there is very strong physical and geological evidence that this rock not only floats the continents, but forms by far the greater part of the ocean floor and ultimately constitutes the deeper-lying parts of the floor in its entirety. Moreover, it is to be inferred from these great outflows that at certain epochs it must become fluid.

As regards the nature of the deep lying materials of the Globe, our knowledge is mainly based upon evidence arising out of seismic disturbances such as now and again transmit to the seismic observatory vibrations originating in the depths.

The reality of Isostasy has been accepted by all who have

studied the subject and has received very conclusive support arising out of the work of Hayford and Bowie in the United States and in the critical work of Heiskanen and others in Europe. Recent observations carried out by Meinesz over the great oceans have revealed exceptions in certain limited areas only: areas over which stresses in the ocean floor are attended by consequent anomalies in isostatic equilibrium. The anomalies are described by Meinesz as being "in good harmony with the universally prevailing opinion that movements of the crust took place here in very recent times and that they may be even still in progress."

Again, in the deeps of the ocean defect of gravitation is observed. Meinesz considers 'that movements of the crust have taken place here in very recent times, and that they may even still be in progress.'

In short, we possess strong evidence that the continents—great as they are—float in a sustaining ocean of congealed but viscous basalt; the space between the continents being occupied by the still lighter waters of the ocean. This condition of structural equilibrium has been attained by the viscous yielding of the rocks to high temperatures and long continued stresses.

We must now approach the subject of mountain genesis. In other words, we have to answer the questions which arise out of the present existence of millions of square miles of up-raised and folded surface rocks largely of sedimentary origin.

As already stated, it is impossible to account for the great phenomena of the mountains, which plainly reveal the former existence of extreme horizontal compressional forces, without the assumption that such forces can only have originated as the result of a shrinkage of the sub-surface materials of the Globe itself. If such a voluminal reduction took place in the great basaltic stratum of the Globe such folding and wrinkling of the floating sial or granitic rocks would find explanation.

But this is not all for which we have to account. The mountains are built—as we have seen—out of materials

which plainly were laid down in formerly existing continental seas and which must undoubtedly have been in communication with the general oceans.

In other words, we have to account for two movements. First, a sinking movement of the land—*i.e.*, of the continents—relatively to the surface of the ocean—whereby the ocean flooded the sunken land areas. And then, secondly, after a very long period of time, during which great deposits of sediments were accumulated in the shallow continental seas, another movement whereby the accumulated sediments were folded and elevated into mountain ranges. And this consecutive sinking and folding of the continental regions of the Earth was several times repeated throughout geological history.

Now these two movements must, obviously, be very different in character and origin. The first is not apparently attended with any marked reduction of the Earth's surface area. There is no attendant folding of the continents. The movement would appear to have been effectively vertical. The second, on the other hand, appears to have been attended with very conspicuous shrinking and folding of the outer crust.

This second movement was followed, or attended by, a re-elevation of the continents and withdrawal of the epeiric seas.

Plainly such a succession of events cannot be supposed to arise out of the age-long shrinkage of a steadily cooling Globe.

We have now to assign a cause for these remarkable movements of the terrestrial surface; and, further, we have to show why they have been repeated several times in the course of the geological history of the Earth.

There exists in the surface materials of the Globe—the continental rocks and the sustaining basaltic substratum—a source of heat practically eternal in its endurance and ceaseless in its genesis.

The radioactive elements which give rise to this inexhaustible supply of thermal energy are present in every rock on

the surface of the Globe. Very many investigations by various methods support this conclusion. The heat-producing elements are more especially abundant in the lighter continental rocks of igneous origin—the granites and syenites, etc.—which largely make up the mass of the continents. The heavier basaltic materials—which float the continents and mainly floor the oceans—also, but in lesser quantities, contain the same sources of thermal energy. Finally, the eclogites—the heavy basalts—which on seismic evidence form the deeper layers of the Earth—are less radioactive still.

The gradient of temperature everywhere observed in deep borings or mines in the continental rocks must be ascribed solely to this thermal source. In fact, simple calculation shows that it is quite adequate to account completely for the temperature gradient. The variability of this gradient from place to place being doubtless due to differences in the radioactivity and thermal conductivity of the rocks involved.

At a certain depth the radioactive continental rocks give place to the less radioactive and heavier basalts, in which, as we have seen, the continents float. Estimates of the probable temperature prevailing at the base of the continental rocks suggest that at their greatest depths the temperature of these rocks must be nearly that of the melting point of the basaltic substratum at its very top. These conditions prevailing in the depths lead to the conclusion that the radioactive heat continually being generated in the sub-continental basalt must, at the present time, be accumulating in its entirety and must ultimately result in the fusion of the basaltic substratum.

Here we must again revert to the well-proved fact of isostasy governing the relations of the continents and the substratum. For arising out of this relationship it is obviously inevitable that the fusion and loss of density of the substratum must involve a sinking of the continents. They must sink for the same reason that a ship sinks a little when it passes from the ocean waters to the less dense waters of the river.

It is this accumulative effect of age-long radioactive energy which brings about the sinking of the continents relative to the ocean; thereby causing the inflow of the ocean waters upon the land and the creation of the epeiric seas. In short, we see that the events responsible for the advent of a great Cycle must be ascribed to the radioactivity of the rocks.

Then a very long period—some fifty millions of years or more—succeeds, during which the rivers flowing into the continental seas deposit therein such sediments as the denudative activity of millions of years may create: such loading resulting in continually progressing submergence of the continental floor. But ultimately certain events put an end to these great preparations for the future mountain ranges.

In order to understand these events we must first refer to the physical history of the oceanic areas of the Earth.

The rocks underlying the oceans and extending downwards for some scores of kilometres are basaltic in character, as we have seen. Now these basaltic rocks—like the rocks forming the continents—must rise in temperature downwards, due to their own proper generation and accumulation of radioactive heat. At a certain depth the melting point will be attained. Beneath that level all the radioactive heat continually being generated will go towards supplying the latent heat required for ultimate fusion. This will require some 50 millions of years—or more—to come about.

Beneath the continents, as we have seen, similar changes are progressing, and from the base of the overlying continents downwards fusion is progressing more and more as the successive millions of years pass away.

Two great events arise out of the general liquefaction of the deep basaltic substratum. In the first place the expansion attending fusion affects the surface area of the entire Earth. It is only very roughly calculable because we know but little as to the compressibility of the fluid basalt. But it seems safe to assume that ultimately it might result in increasing the surface area of the Globe by some 1,700,000 square kilo-

metres (650,000 square miles). This estimate omits effects due to volume-change of an eclogitic substratum. The specific volume-change affecting such a substratum would be *not less* than some 20 per cent. in excess of that of a normal basalt.

Now this great increase in the volume of the substratum must result in general tensile forces affecting the still solid floor of the oceans and of the overlying continents. For, in fact, the whole surface has to grow larger in order to accommodate the expansion of the sub-surface materials. Rents will develop in the ocean floor and basaltic lava will be poured out and many volcanic islands will come into existence. Such rents are possibly traceable in the remarkable parallel-linear distribution of the oceanic islands of the Pacific, and have probably given rise to the great lava-flows along the ocean margins—*i.e.*, the Hebridean and Deccan traps, etc., as already referred to. Such great tensile effects as have rent the African continent would also find explanation in these deep-seated volume changes of the Globe.

But a second important—indeed, critical—event also comes about and one which averts much of the danger of cataclysmic results developing and gravely affecting the stability of the continents. In order to understand clearly the event referred to we must look back to a foundational and now well-known mathematical investigation due to Professor Love. The investigation had reference to the question as to the possible existence, at the present time, of a fluid layer beneath the outer crust of the Earth. Love found that such a layer cannot now exist; for, if it did, effects upon the oceanic tides must reveal its existence. There might be patches of molten matter here and there, but a continuous fluid layer there could not be.

A general understanding of Love's investigation is easy. The solar and lunar gravitational attraction, as tending to withhold preferentially the outer crust towards the west, would, in the case of a fluid layer underlying the continents and ocean floor, give rise to movements of the outer crust relative to the inner core, so that the deeper layers would

gain upon it in the general west-to-east rotation of the Earth.[1]

The importance of this conclusion in the past history of the Earth cannot be over-rated. It explains why the radioactive conditions which affect the outer materials of the Globe have not resulted in the destruction of all life upon its surface. It confers upon the oceans yet another function in the biological history of the Earth.

For, as we have already seen, at a certain stage in the progress of a great Revolution a deep fluid layer must develop beneath the continents and beneath the water-cooled ocean floor. The slow relative movement westward of the rigid outer crust, consisting of the continents and ocean floor, must result in the highly heated sub-continental lavas being brought beneath the ocean floor. Through this floor the superfluous heat escapes into the ocean throughout the succeeding ages, and the continental layer is thereby saved from destruction. Many millions of years may be involved in these movements.

There is good evidence in the foundering of marginal continental tracts—such as those forming the eastern extension of Asia and those known to have formed, in remote times, a part of Eastern North America—for the former existence of these conditions. For such cataclysmic faulting and foundering of great tracts can only be accounted for by the melting away of the supporting compensations.

We notice that the preservation of life upon the land is not obtained at the cost of life in the ocean. Its waters convey away the escaping heat with but little rise in temperature. The resolidification of the entire basaltic substratum is ultimately brought about in this way.

Attending the escape of the accumulated heat from subcrustal depths the successive events of a great Revolution are being further developed at the surface of the Earth. For the thermal loss involves the voluminal shrinkage of the entire substratum and concurrent, ever-accumulating, pressure con-

[1] See also a lecture by Sir Arthur Eddington, "On the Borderland of Astronomy and Geology," *Nature*, January 6, 1923.

ditions in the surface rocks. The applied force may be regarded as derived from the ocean floor, the thickness of which as a rigid body may be taken as some 30 kilometres at this time.[1]

This solid crust bears everywhere against the continental coasts. In some regions very slowly and irresistibly crushing the accumulations and flood of the epeiric seas and uplifting them into mountain chains.

The yielding of the continental structure arises naturally and inevitably out of the prevailing conditions. For on the one hand the continents are at this period more heated than the ocean floor. A fact due not only to their much greater radioactivity, but also to the absence of a universal overlying ocean of vast depth and thermal capacity such as cools the sub-oceanic basalt. Again, the continental rocks do not possess the homogeneity of the great basaltic sub-oceanic layer. Finally, the compressional strength of basalt among rocks is exceptionally great, if not the greatest known, and far above that of the secondary rocks entering into the continental surface structure.

It is interesting to consider what is actually involved in sub-continental events attending a great Revolution. In the first place we recognise that in the substratum there exists a continuous and inexhaustible genesis of heat. We know this from our knowledge of its basaltic character and our extensive knowledge of these rocks. *In the depths such a substratum must ultimately melt. But Love's result shows that a general fluid layer exists nowhere at the present time among the outer materials of the Earth. Taken together these two conditions can only be reconciled in one way: the former occurrence of the Revolutions. For in this periodical manner only is it possible for the accumulated heat to escape through the ocean floor.*

How long might these successive events require for their development and consummation?

Calculations based on direct measurements of the radio-

[1] *The Surface History of the Earth,* second edition, p. 203.

active contents and latent heat of many scores of samples of the rocks concerned suggest the lapse of some 48 or, say, 50 millions of years for the upper layers of the substratum.

Beneath the oceans the basaltic substratum is continued. In the case of the Pacific the basalt reaches nearly to the waters of the ocean. In the case of the Atlantic it is believed to be overlain by a layer of continental materials.

Preceding the advent of a Revolution we may assume that, in the case of the Pacific, the solid sub-oceanic basaltic floor is approximately at 0° C. at its surface, the temperature rising slowly downwards until a depth of about 32 kilometres (20 miles) is reached, beneath which the escape of heat becomes very slow. This estimate is due to J. R. Cotter (*Phil. Mag.*, September, 1924). Heat generated above this depth escapes into the ocean. Beneath it the heat accumulates much as heat accumulates beneath the continents. As we have already seen, some 120 millions of years might be required in order to bring about the liquefaction of the deeper parts of the substratum. These figures are closely related to such estimates as we can arrive at respecting the time-period required to bring about a Revolution. For we may consider that at the close of a Revolution the basaltic layer is left in a condition of solidity; the preceding Revolution resulting in the loss of the latent heat of fusion and the regrowth of the basaltic ocean floor from its (practically) limiting depth of 32 kilometres upwards. Above this depth the radioactive heat escapes slowly into the ocean. Beneath this depth it accumulates. As stated above, liquefaction would ensue in some 120 millions of years.

Estimates of the antiquity of the ancient rocks based on the analysis of ores of uranium and thorium have been repeatedly attempted. It is assumed that the rate of radioactive changes in these ores will be constant over geological times. In both cases the final product is lead: the lead being different in atomic weight from ordinary lead and different also according as it is derived from uranium or thorium. Results exhibiting very often unaccountable disagreement

have been obtained in this manner. Lately Clarence A. M. Fenner records (*Am. J. of Science*, November, 1928) concordant results obtained by such measurements. He takes special precautions against the presence of decomposition products, etc. He obtains the same 'age' from both ores—*i.e.*, 360 millions of years.

On the subject of the time-periods involved in the Major and Minor Revolutions we do not seem able at the present time to advance any further than we have gone. It must suffice to keep in view the strong evidence for both longer and lesser time-intervals between crustal disturbances as arising out of the surface structure of the Earth. We may claim to have arrived at data enabling us to account for lesser Revolutions arising out of more superficial thermal accumulation and for greater Revolutions wherein the depths of an eclogitic layer 60 kilometres deep are involved; and possibly, along with this, thermal accumulations nearer the surface. That there would be a certain degree of rhythm affecting the Revolutions is obviously to be expected.

We turn to the bearing of the foregoing theory of Earth-history on the Geographical features of the Globe.

(*a*) The relative areas occupied by land and water can be traced to factors which limit continental thickness. Obviously, given a certain definite amount of the lighter, more acidic, continental materials as segregated out of the universal basaltic layer, the area occupied by these materials must depend upon the depth of aggregation.

Now the total continental depth is controlled within certain limits by considerations arising out of their radioactivity. For the basal temperature, due to intrinsic radioactive content, varies as the square of the continental depth. If this depth is sufficiently great heat will flow downwards into the underlying magma and temperature conditions may be attained during the prolonged period of thermal accumulation which will soften and ultimately melt the deeply submerged continental materials. In this event the fluid material would escape from beneath the continent and during the tidal movement of the outer crust would emerge

principally on the eastern continental margin. This effect is supplemented by denudative degradation at the surface which also tends to spread the continent laterally. Acting in the opposite direction, during the orogenic period the compressive forces proceeding from the ocean floor fold up the geosynclinal deposits and tend to restore the original continental thickness.

Under the play of these opposing effects the continents as we know them have been moulded, and, of course, the water collected at the earth's surface must occupy the residual area: the mean oceanic depth being defined by the extent of that area and by the quantity of the water.

At the present time there are considerable differences in the mean emergence of the several continents. Obedient to isostasy, a highly emergent continent corresponds to a greater mean submergence. But we live in the period immediately following a great revolution, and the effects of the mountain-raising forces must continue unmodified for long ages to come. Doubtless the slow adjustments, arising out of excessive thermal accumulations beneath, account for a considerable part of inter-revolutionary fluctuations of level and even local orogenesis, such as have been recorded in many parts of the world and at divers periods in its surface history.

(*b*) The distribution of land and water upon the surface of the globe is not what would have been expected upon a planet possessing so great an axial velocity. There are, indeed, forces arising out of this high velocity which urge the elevated features of the crust—*i.e.*, the continents—towards the equator. These forces are feeble, but they have been in operation all along and may have been greater in the past. Nevertheless, the disposition of land and water is far from being equatorial. Quite the opposite, we may say, because a distinctive geographic feature of the globe is the existence of seas extending without interruption from pole to pole. The small Antarctic Continent cannot be regarded as qualifying this statement.

The explanation of this geographic feature of our world is to be found in the simple fact that any other disposition

must be unstable and could not persist over geological time. A belt-like continent encircling the globe parallel with the equator would infallibly break up under the conditions leading to a great revolution. For the discharge of sub-continental heat into the ocean could not take place. The tidal drift of the surface crust which, under the present geographic disposition of land and water, brings about this discharge would be powerless to effect relief if such movement left the emergent land still blanketing the underlying substratum with an adiatherminous covering. Under the stresses arising from the expanding substratum the encircling land mass must rupture, doubtless along rifts extending in longitude, for no ocean floor would intervene to take up the stresses acting in latitude. As the radioactive heat went on accumulating the basal rocks of the continents must ultimately soften and liquefy. Thus we can see no other ending than a general break up into insular forms.

These considerations lead us, in fact, to the view that the extension of the continents in longitude and their severance by broad oceans must be the most stable disposition under the conditions arising out of a radioactive substratum. That this disposition is predominant in geography would be better appreciated if we could contemplate the earth after the depth of the ocean was reduced by a few hundred fathoms. Australia would then form the southern termination of a great meridional extension of the land towards the south.

(*c*) The relatively minute vertical scale upon which the raised surface features of the Globe are modelled arises necessarily out of the instability which assails compensations extending beyond a certain depth into the substratum. Thus it can be shown that the Tibetan Plateau approaches the limits of stability. So greatly extended a mass must find full isostatic compensation. If its internal temperature has now reached a steady state there must be a considerable downward flux of heat into the substratum and an interior temperature approaching the softening point of quartz. Its stability as a whole, however, may be adequate, for this only applies to a limited central region; but it is evident that

much greater surface features would not be stable. The mountains are, of course, not individually compensated. The stiffness of the crust distributes the load. In this way the surface features may attain locally elevations which could not be maintained over large areas. Thus, ultimately, we find that, except for small surface features, the existence of a radioactive substratum and the great fact of isostasy govern the vertical relief of the globe.

(*d*) In the past, at long intervals and in the periods immediately succeeding the great revolutions, cold climatical conditions have affected the whole surface of the globe and left many geographic features behind them. Many geologists ascribe this effect as largely due to conditions of general high elevation of the land. It is a not improbable explanation. When the substratum finally consolidates and the compensations are pushed upwards it is doubtless true that the average continental level is for a period very high. Data respecting the elevation of the land in Pleistocene times are not always consistent, but the general high level of the North American continent at that period seems to be certain.

The meteorological effects of a general continental elevation by a few hundred metres may be considerable and, not improbably, self-intensifying. But this matter has been already discussed by many writers and need not be dwelt on here.

(*e*) The principal geographic effects arising out of the periodic liquefaction and solidification of the substratum are to be witnessed in the mountain systems of the earth. Whether the entire work of orogenesis be ascribable to the alternate enlargement and reduction of the surface crust or whether they are in some part referable to forces attending the tidal shifting of this outer crust, cannot here be discussed. The latter possible source of orogenesis has yet to be quantitively evaluated. Meanwhile we are safe in ascribing to the changing area of the Earth's surface by far the larger part of mountain development over geological time.

The orogenetic movements need not necessarily take effect close to the continental margin, although it is probable that

there the stresses are greatest and there the primitive elevation which initiates the geosyncline is most likely to originate. But in the case of the mountain systems of Eurasia there is plain evidence of the transmission of stresses far into the interior. Some bodily movement of the African Continent and of India may even have taken place. A movement easily understood when it is remembered that the compression in longitude was developed over the greatest ocean stretch of the Globe. The wrinkling of Asia to its centre by these great stresses and the opposing ones acting from the North need not excite credulity; for, in fact, the horizontal stresses must be conveyed through the entire surface crust of the earth. We may be sure that wherever the geosyncline has been formed and an area of feeble resistance created the horizontal compressive stresses will find it out.

LIFE

The surface history of the Earth embraces the history of life upon the Globe. Without the fossil of the once living organism we had known but little of historical geology. In the recognition of the ubiquity of the organism in terrestrial space and its restriction in time Stratigraphical Geology originated. In these concluding pages I shall enter a little way into the subject of Life and its attributes as these affect our subject.

The study of the rocks tells us that life dates back to very early times. Many geologists refer the first appearance of life upon the Globe to Archæan (Archeozoic) times. They consider that in certain rocks laid down in those remote ages there is evidence for the existence of the less complex forms of life such as algæ and bacteria. Henceforward the history of life upon the Globe has been one of continual expansion. Abundant life has penetrated even into the greatest depths of the oceans; surviving the unchanging icy temperatures of the great depths and living and multiplying in sunless regions.

Considering its marvellous aggressiveness we may well ask: In what manner is the organism distinct from the rest of Nature—the rocks, the waters, the atmosphere, the sunshine? . . . Plainly it differs in its properties from all these.

Many years ago, when wandering in the Dolomites of South-East Tyrol along with one who is now the learned Professor of Botany in the University of Dublin,[1] the foregoing question was presented to us with special force by the nature of our surroundings.

We had reached the Pass of Tre Croci, and, from a point a little below the summit, looked eastward over the glorious Val Buona. The pines which clothed the floor and lower slopes of the valley extended their multitudes into the furthest distance among the many recesses of the great mountains and into the confluent Val di Misurina. In the hot sunshine the Alpine butterflies flitted from stone to stone. The ground at our feet and everywhere throughout the forests teemed with the countless millions of the small black ants.

It was a magnificent display of vitality—of the aggressiveness of vitality—assailing the heights of the limestone and wringing a subsistence from dead things. And the question presented itself with new force: "Why the abundance of life and its unending activity?"

In endeavouring to answer this question we may, in the first place, offer a definition of the living organism as being "a material structure which absorbs energy acceleratively from its surroundings."

The meaning of this statement is apparent if we consider a simple case: that of vegetable growth. The leaf exposed to solar rays enlarges because of the effects of the radiant energy which it receives, and, in doing so, it absorbs more of the rays.

It is certain that this simple principle is at the basis of all organic life. It applies to the smallest microscopic organism

[1] Professor H. H. Dixon, F.R.S., Proc. Royal Dublin Soc., vol. vii., 1890.

and to the greatest inhabitant of the forests or of the ocean. In such an evident dictum we recognise the basis of the whole of evolutionary life upon the Globe. Its struggle for existence; its power of self-reproduction; its trials in every direction for fresh energy supplies; its wonderful ingenuity in securing and making use of them.

We may contrast the attitude of living and dead nature somewhat as follows:

"The transfer of energy into the animate material system is attended by effects conducive to the transfer and retardative of dissipation."

Of the inanimate material system we may say: "The transfer of energy into an inanimate material system is attended by effects retardative of the transfer and conducive to dissipation."

The student of thermodynamics will recognise in the last statement the second law which involves that whenever work is derived from heat a certain quantity of heat falls in potential without doing work and is dissipated. On the other hand, work may be entirely converted into heat. The result being the heat-tendency of the universe. Heat being an undirected form of energy seeks, as it were, its own level, so that the result of this heat-tendency is continual approach to uniformity of potential.

We must regard the organism as a material structure which is so contrived as to evade or delay the tendency of the more fundamental law of dead nature: the tendency towards loss of potential. It may, indeed, absorb and accumulate energy without limit when unconstrained. The facts and generalities concerning evolution must presuppose an organism endowed with the quality of the progressive absorption of energy and of its retention. The continuity of organic activity in a world where supplies are intermittent is only possible upon the latter condition.

We can trace the periodic succession of individuals on a diagram of activity with some advantage. Considering, first, the case of the unicellular organism reproducing by subdivision and recalling that conditions, definite and inevitable,

oppose a limit to the rate of growth, or, for our present purpose, rate of consumption of energy, we proceed as follows:

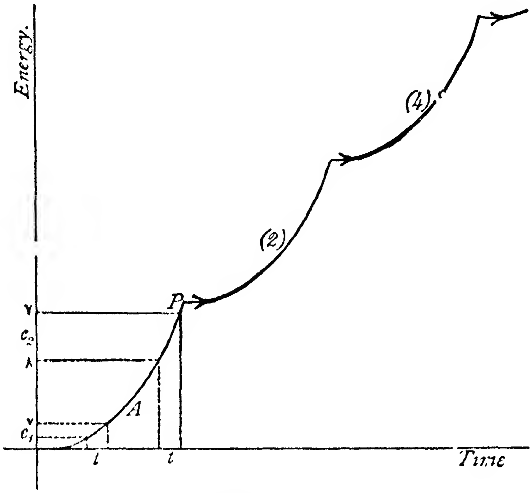

FIG. 1.—LIFE-WAVES OF THE AMŒBA.

Along a horizontal axis units of time are measured; along a vertical axis units of energy. Then the life-history of the amœba, for example, appears as a line such as A in Fig. 1. This line starts at the point of origin of the axes of reference. During the earlier stages of its growth the rate of absorption of energy is small; so that in the unit interval of time, t, the small quantity of energy, e_1, is absorbed. As life advances, the rate of activity of the organism augments, till finally this rate attains a maximum, when e_2 units of energy are consumed in the unit of time. At any moment of its life, the rate of activity, $\frac{de}{dt}$, is represented by the trigonometrical tangent of the angle made with the axis of time by a line tangential to the curve at the point in question.

On this diagram a reproductive act, on the part of the organism, is represented by a line which repeats the curvature of the parent organism originating at such a point as P in the path of the latter, when the rate of consumption of

energy has become constant. The organism A has now ceased to act as a unit. The products of fission each carry on the vital development of the species along the curve B, which may be numbered (2), to signify that it represents the activity of two individuals, and so on, the numbering advancing in geometrical progression. The particular curvature adopted in the diagram is, of course, perfectly imaginary; but it is not of an indeterminable nature. Its average course for any species is a characteristic of fundamental physical importance, regarding the part played in nature by the particular organism.

It matters not if the duration of individual life be long or brief. Brevity of life is generally associated with rapid reproduction. The principle is the same, even for the most ephemeral; those born with the rising of the sun and dying with its setting: life, love and death encompassed in a day.

Thus we see in the abundance of life around us a marvellous display of ingenuity. Each individual, whether great or small, during its life strikes out a 'curve of activity' where the ordinates are energy and time. Inability to prolong the curve indefinitely is evaded by reproduction so that the activity of the new generation becomes the many-branched repetition of the worn-out parental curve. The entire succession still ever advancing towards increasing animate energy.

The result of the whole wonderful phenomenon is that nature around us thrills with the presence of the animate notwithstanding the fact that death remorselessly awaits the individual. For although the individual dies death is not the end: life being a rhythmic phenomenon.

Through the passing ages the waves of life persist. Waves which change in their form and in the frequency to which they are attuned from one geologic period to the next. But which still ever persist and still ever increase. And in the end the organism outlasts the generations of the hills.

ASTRONOMY AND SCIENTIFIC IDEAS

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IT is a fact of experience that no account of modern astronomy can protect itself from misinterpretation unless it insists in the clearest terms that it is mostly untrue. This is not criticism but definition: it expresses the fact that the greater part of modern activity in astronomy is concerned with the construction of an ideal model of the universe and its contents out of insufficient knowledge. There is nothing in this with which to reproach the astronomer; he acts as he does for a perfectly legitimate purpose, and is not as a rule unduly prone to attribute permanent reality to the temporary creations of his brain. His purpose is complex, but its chief element is the desire to obtain more knowledge. He can do this most effectively by trying to arrange his present store into a self-consistent whole, the difficulties which he meets with in this operation being his most suggestive pointers to new knowledge.

The chief danger of the popularisation of science at the present time is that the tentative character of scientific theory may be forgotten. It is not, however, the only danger. The fact may be remembered too exclusively. If astronomy speculates she speculates on a basis of established knowledge, and to question the knowledge because the speculation is hazardous is possibly even more foolish than to give free rein to credulity. The actual discoveries of modern astronomy are only less impressive than the implications of its theory, and whatever changes in outlook, whatever improvements in the means of observation, and whatever new discoveries may be made in the future, they will remain as permanent

elements of our knowledge. We hail a theory with hope, but we accept a fact with conviction.

If, now, we are led from these considerations to suppose that modern astronomy can be sharply divided into fact on one hand and theory on the other, we shall greatly err. The transition is gradual, and while of some notions it may unequivocally be said, "This is theory and that is fact," there is a very large portion of the subject which cannot be compressed into such a limited classification. This point is of the greatest importance. We are no longer so hot for certainties as we were, the dusty answers of past generations having tempered our ardour in this respect, but we do want to know what particular small department of our knowledge is certain and what degree of probability we can safely attach to the remainder. The question is difficult, and is evidently not to be fully answered in a small compass: we must attempt an answer, nevertheless, because of its importance.

To begin with, we may accept the evidence of direct general observation of the existence of bodies as certain; otherwise science has no basis. Without entering into metaphysical discussions, we may to direct observation add observation at the telescope and by photography. When we say that a certain region in *Perseus* contains at least 20 nebulæ, we are making a statement which time will not disprove. Determinations of distance stand on lower planes of certainty, although in many instances, when their range of possible experimental error is given, they may be accepted as beyond correction. No astronomical distance can be measured as a cricket pitch is measured, by laying standardised rods or a standardised tape along its length. Less direct methods have to be chosen; *e.g.*, the process of triangulation used in surveying large areas of terrestrial land. By this means we find that the mean distance of the Sun from the Earth is 92,870,000 miles, with an error of less than one-tenth of 1 per cent. Mr. Bernard Shaw, on being told of this figure, is reported to have expressed astonishment at the magnitude of the lie. If it is a lie, however, we must say that

the statement that Mount Everest is approximately 29,000 feet high is also a lie, for both figures are obtained by the same means and according to the same principles. We may take the distance of the Sun as scarcely less certainly determined than its existence.

The distances of the nearer stars are found in the same way—with, however, a greater possible range of experimental error—but for the more distant stars other methods must be employed. For instance, when we know the distance of a star we can calculate its intrinsic brightness, and on so doing we find among the nearer stars a definite relation between the brightness and the kind of light a star sends out. Observing, then, the kind of light sent out by a distant star, we infer its brightness and then calculate its distance. Distances found in this way are clearly less certainly determined than the distance of the Sun. Not only is the margin of possible error greater, but the conclusion that what we are measuring is actually the distance of the star involves certain assumptions which we cannot absolutely prove to be justified. When we extend the process to still more distant regions of space the hazard becomes greater, and so we find some astronomers maintaining that the stellar system is many times as extensive as others believe it to be. The difference is mainly not a matter of inaccurate measurement, but a consequence of the fact that various indirect methods are employed and astronomers have varying ideas of their relative degrees of validity. We evidently get further and further from absolute certainty as we recede in space.

Still further circumlocution characterises our descriptions of the velocities of bodies. Velocity on the Earth is measured by the space traversed in a chosen interval of time: velocity in the sky is chiefly measured by the positions of lines in the spectra of the bodies concerned. To establish the identity of the concepts which are said to be measured by these widely different processes we should have to prepare a statement of considerable length including a little experimental evidence and some assumptions. The statement may be convincing—it usually is, in fact—but in the last resort it rests

on circumstantial evidence, not on rigid proof, and certain of the more recently measured velocities lead to such remarkable conclusions that some astronomers are seriously questioning whether what has been measured is really "velocity" in the ordinary sense or something quite different.

When we come to the problem of the physical conditions existing in the heavenly bodies we are in the realm where theory predominates considerably over fact. The surface temperatures of stars, for instance, range from highly probable values, such as that of the Sun, to others which we are forced to qualify by such terms as "colour temperatures" or "ionisation temperatures" to distinguish the sometimes widely differing results obtained for the same star when the necessary assumptions which must be made are different. In the interiors of stars, matters are far more speculative, for of these regions there is no observation at all to guide us. Consequently we find a modicum of agreement almost completely overwhelmed by a confusion of conflicting ideas. No one can say how much of our present picture of stellar constitution will survive in ten years' time, but very few will expect more than a small portion.

Finally, when we come to the universe we are in a realm of pure theory. Not only have we never beheld the universe, but our speculations themselves involve the impossibility of our ever doing so. There is not a single statement which we can make about the universe as a whole with even the certainty belonging to our knowledge of the velocities of the stars. The universe of astronomy is a creation of the astronomer's mind.

It is important that these ideas should be expressed, but it is equally important that they should not be misapprehended. They are applicable not only to astronomy but to all science and to ordinary daily life. A discussion of astronomy calls for their emphasis only because the proportion of certain knowledge is smaller there than in most sciences and because for some reason men are prone to base their theologies and philosophies more on the great and the unknown than on the ordinary familiar commonplaces of experience.

To such as are ready to dogmatise about the character and attributes of Deity from the "revelations" of astronomy, it is necessary to point out the nature of the ground on which they stand, but if there are any who thereupon turn from astronomy as from a tissue of arbitrary guesswork, they must be reminded that the scrutiny to which we have here subjected astronomy would leave scarcely one of their ordinary instinctively adopted notions unchallenged. If our knowledge of stellar distances is indirect, so is our knowledge that Napoleon was defeated at Waterloo. The velocities of the stars are established with no more uncertainty than the commission of any unwitnessed crime; and we are entitled to speak with greater confidence about the internal condition of a star than about the internal condition of Russia. The real significance of the last few paragraphs will be dealt with at the end of this chapter. In the meantime let us hear what modern astronomy has to say, and suspend our judgment of its value.

The solar system, of which our Earth forms a part, was once the centre of astronomical interest. It is now comparatively neglected. This is not because it has no secrets yet unread or because our devices for reading them are exhausted; it is because we have changed our point of view in order to scan the universe from the most advantageous angle, and from the new viewpoint the solar system is scarcely perceptible. Stress must be laid, however, on the comparative nature of this neglect. Judged by the standard of a hundred years ago, our present discoveries in the solar system are sensational: it is only against the background of stellar astronomy that they are inconspicuous. During 1931 the discovery of 13 comets made scarcely a ripple on the sea of astronomical knowledge; 200 new minor planets were found in the system, but no astronomer's heart was thereby made to beat faster. A few years ago the discovery of a new major planet, now known as Pluto, created a mild interest which has already died down, whereas the echo of a similar discovery in 1846 reverberated to the end of the nineteenth

century. The Sun, it is true, attracts considerable attention, but not as the ruler of our system. It is studied because it is the unit of the galactic host which happens to be nearest to us. Modern astronomy, like Swinburne's God, "gives a star and takes a Sun away."

One question, however, of universal interest has not been outgrown—the question of the origin of the solar system. Laplace's nebular hypothesis, which in the main satisfied the nineteenth century, is unequal to the demands of the twentieth. The present idea—that the planets were born from a primitive Sun by the very close approach or actual impact of another star some few thousand million years ago—owes its acceptance largely to the absence of an eligible rival. There is an instinctive feeling against it because of what is technically called the "improbability" that such an event would happen. The stars are so distant from one another that, according to a current estimate, a sufficiently close encounter would be experienced by at most one in every 100,000 of them. It is felt that there is something of the nature of special pleading in claiming this apparently forlorn hope as the source of our existence.

The feeling is illusory. The mathematical laws of probability have no meaning in relation to a single arbitrary case. It was exceedingly improbable that a particular Mr. X would win a large prize in the Irish sweepstake, but it was certain that an arbitrary Mr. Y would win one; and even if, as in the present problem, certainty is out of the question, it is exceedingly probable, as Aristotle long ago remarked, that the improbable will sometimes happen. If it be objected that it is highly improbable that such an odd chance should happen to us of all beings, the answer is that it did not happen to us. It happened, if the hypothesis is true, to a quite ordinary, undistinguished star. The fact that we developed on a planet of such a star rather than elsewhere is then (granting that we were to exist at all) not a matter of luck but of inevitability, for life as we know it could not have developed anywhere else. If that star had not suffered disruption we should not have developed around it but

around one which had. Whether chance or design be responsible for our existence, the present theory of the genesis of the solar system is *a priori* equally justifiable; it is to be judged solely on its ability to fit the facts of observation. And, conversely, it throws no light at all on the problem of whether we exist by chance or by design.

The solar system, as we now know it, occupies a roughly circular area, some 7,500 million miles in diameter. Compared with the distance of the nearest star—namely $1\frac{1}{3}$ parsecs[1]—this is to be regarded as a point. Nevertheless, the Sun is not abnormally isolated in space. Except for the components of double and multiple stars—systems comparable with the solar system so far as their demands on space are concerned—the stars which form our galaxy are separated on the average by distances of a parsec or more. The diameter of a single star may be anything from a few tens of thousands to a few hundreds of millions of miles—in any case a point compared with its surrounding region of interstellar space. It is truer to say that space is empty of stars than to say that the purest water is free from deadly germs.

In such a vacuum it seems somewhat ridiculous to speak of the stars as "thinning out," but since all distances are relative, the phrase has a perfectly definite meaning. If we could travel without limit in a straight line from the Sun towards the Great Bear, for example, and could measure *en route* the average distance between the stars, we would find that after a while this distance would steadily increase until we reached a region where, over a range of hundreds of thousands of parsecs, space was *absolutely* empty. The same thing would be true of other directions of travel, but the distance to which we would have to pierce before reaching this absolute void would be different in different directions. This means that if we could transport ourselves to a viewpoint, say a million parsecs away, and look back towards the region we had left, we should see an isolated company of stars with rather vaguely defined boundaries. This is our *galaxy*, our *galactic system*, our *stellar system*, our *universe*

[1] 1 parsec $= 3\frac{1}{4}$ light-years $= 19$ million million miles.

—it is called indifferently by each of these titles. We will shun the last-named, however, reserving it for the totality of physical existence, for although the galaxy is vast beyond imagination, it is a mere speck in cosmic space—one of millions of specks of comparable dimensions. To call each of these a "universe," as is sometimes done, is to imply that they are unrelated to one another, which is untrue.

In our galactic system the Sun occupies a highly eccentric position. It is, however, well inside the boundaries, so that we have the thankless task of surveying what is probably an organised system from an internal point. The survey, both of dimensions and of form, is consequently far from complete. We may obtain some guidance, however, from a study of other galaxies of which we can command a bird's-eye view. We find them presenting various forms, but the form which, from both internal and external evidence, seems most likely to be the form of our galaxy is that of the so-called "spiral nebulæ," of which an example is shown in Fig. I. The best available photographs of a few of the apparently largest (and therefore probably nearest) of these objects show that the nebulous-looking arms are crowds of discrete stars, perhaps as sparsely distributed as those of our own neighbourhood, but at the great distances of the nebulæ appearing as dense swarms. The nearest of the spiral nebulæ is nearly a million light-years away. We may provisionally assume that we inhabit one of the arms of a spiral nebula.

Investigations of the distribution of stars within our galaxy support this hypothesis. The plane of the spiral is that of the Milky Way, which is, in fact, the appearance presented to our eyes by the great depth of star-strewn space through which we inevitably look when we turn our eyes towards the periphery of the system. Fig. II gives some idea of the apparent density with which the stars are scattered in the Milky Way, but it must be understood that the appearance of crowding is due almost entirely to the *depth* of space through which we are looking. The actual distances between the stars are not appreciably greater than those which separate the Sun from its neighbours. The difficulties of the task of

Photo: Richey.

Fig. I.—Spiral Nebula. M.33 Trianguli.

Photo: Barnard.

Fig. II.—Great Star Cloud in Sagittarius.

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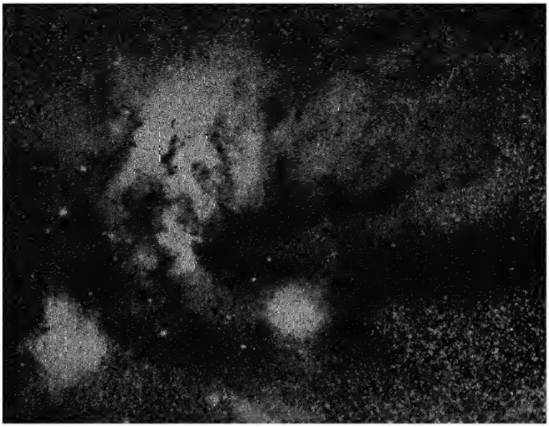

Photo: Barnard.

Fig. III.—Region of ρ Ophiuchi.

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determining the structure and organisation of our system from such photographs as this can readily be imagined, and the statement that present results must be accepted only tentatively will not be found hard to accept.

The difficulties are greatly increased by the sporadic occurrence in our galaxy of dark diffuse nebulæ[1]—patches of obscuring matter, of which examples may be seen in Fig. III. The uncertain amount and situation of this material (whose composition is unknown, though there are some not universally admitted grounds for believing it to be a mixture of dust and gas) gives some uncertainty to all measures of the extent of the system. For example, in the direction which various phenomena indicate as that of the centre of the galaxy, the stars should extend to the greatest distance from us, but this appears as by no means the brightest portion of the sky. In spite of these difficulties, however, some idea of the dimensions of the system has been formed. The greatest diameter appears to be between 20,000 and 100,000 parsecs —the estimates vary considerably within this range—while the thickness is much less—perhaps 1/20th or 1/30th of this figure. The two nearest of the spiral nebulæ, if our estimates of their distances are correct, are about 14,000 and 5,000 parsecs, respectively, in extent. These figures, though considerably smaller, are evidently comparable with the dimensions found for our own system.

The coiling arms of the spiral nebulæ inevitably suggest rotation, but their great distances make it impossible, unless the velocities are incredibly great, that we should obtain direct knowledge of this in the short time during which they have been studied.[2] In our galaxy, however, we have definite evidence of rotation. The stars travel round the centre of the system, not as a rigid wheel in which all parts go round in the same time, but in the manner of the planetary

[1] The common name, *nebulæ,* for the spiral and diffuse nebulæ, must not be allowed to cause confusion between objects which are essentially different in character.

[2] There is, however, spectroscopic evidence of rotation of certain nebulæ which we see edgewise.

motions round the Sun, the stars farthest from the centre taking the longest time to complete a revolution. This difference in period, in fact, affords the most obvious evidence of the revolution. It is calculated that the Sun, which, according to the larger estimates, is of the order 25,000 parsecs from the centre, takes 250 million years to complete its circuit: this implies that it has travelled round five or six times since the Earth became a solid body.

The galactic system contains, according to current estimates, some 100,000 million stars. Certain specific lines of inquiry suggest that it has been in existence, in at any rate something approximating to its present condition, for many million million years, but more general considerations point to an age of the order ten thousand million years. Which figure is to be preferred is a matter of opinion. It is much to be hoped, however, that the data will soon become less equivocal, for the question has a very close bearing on the important problem of the evolution of the stars. Since the stars send us light, which is a form of energy, we must believe that they are undergoing certain internal changes which, however slow they may be, must ultimately have profound effects on their constitution.

The problem of the life history of a star is one which the progress of the last few years has seemingly tended to obscure rather than to clarify. The nicely rounded-off theory of a decade ago is now sadly dishevelled. This, however, gives no cause for dismay; it is a familiar experience in the advance of knowledge. "When the half-gods go, the gods arrive," but the half-gods must go first. The older theory was formed mainly as a means of correlating the directly observed characteristics of the stars—their brightnesses, spectral types, and so on. It did this excellently, except for one or two puzzling faint stars which, then regarded as freaks, are now recognised to be probably as numerous as stars of any other kind. The existence of these bodies (the "white dwarfs," as they are called) would be sufficient in itself to cast grave suspicion on the theory, but historically what led to its overthrow was not so much new facts as a new kind of demand on the

character of a theory of stellar evolution. Such a theory was required to explain not merely direct observations, but the hypothetical conditions inside the stars, which were deduced according to the laws of physics from what was observed. The course of stellar evolution which is sought now is one which will be expressed in terms of changes of energy and the behaviour of electrons, neutrons, protons and "photons," as unit quantities of radiation are called. When it is found it will trace out directly the internal development of a star from birth to death. The concomitant changes of observable characteristics will be rigidly deducible from it, but will not, as formerly, provide the language in which it is expressed.

The *sine quâ non* for such a theory is therefore a definite and accurate idea of the state of the stars now, and this we do not possess. The problem of stellar constitution was, in fact, until lately the centre of perhaps the most vigorously conducted discussion in modern astronomy, and the present comparative quiescence is merely a pause for the acquisition of fresh observational data. The situation is of extreme interest, no less psychologically than objectively. The problem, in the most general terms in which it is considered, can be stated very simply. Given certain observations of the stars and certain general laws of physics, it is required to determine to what conditions ordinary material must be subjected in stellar interiors in order that, when behaving according to those laws, it shall give rise to what is observed. This problem will repay a little attention, for its consideration throws light on both astronomy and the habits of astronomers.

In the first place, it will be noticed that the problem has not been stated in the most general form in which it can be conceived. There is no *a priori* necessity to assume that the stars shall consist of ordinary material or that their constituents shall obey the laws of terrestrial physics. All astronomers, however, make both these assumptions, and in doing so they are simply conforming to the general canons of scientific method enunciated by Galileo in opposition to the Aristotelian doctrine of a fundamental division in Nature between the incorruptible Heavens and the corruptible Earth. There is no

rash presumption involved in this conformity. If the substance and behaviour of the stars differ from those of earthly bodies, then the efforts of theoretical astronomers will be fruitless and the difference will thus be made manifest in the only possible way. If, on the other hand, the observations are successfully accounted for, then that fact will constitute a justification of the assumptions made. Those assumptions are thus not unquestionable dogma but simply instruments of research. To a considerable extent they have already justified themselves. For example, the atmospheres of stars give spectra identical with those of terrestrial elements, and the movements of double stars conform to the law of gravitation. There is therefore empirical as well as rational ground for maintaining the assumptions, and there is complete unanimity among astronomers in so doing. It must be said, however, that by "ordinary material" is not meant the ordinary atoms which compose our matter, but the electrical particles which form them. We do not postulate for the stars anything but the *ultimate* constituents of the Earth. If, by further research, the electron and proton are broken up into sub-electrons and sub-protons, these will become the elementary particles of stellar theory and the possibility of their amalgamation into systems different from those of the electron, neutron and proton will be taken into account. But until such a discovery is made its possibility is not considered.

Admitting this common starting-point, however, the remaining problem still offers ample scope for difference of treatment. We begin with certain data and aim at the underlying conditions responsible for them. Two conceivable courses at once suggest themselves: we can attempt to deduce the conditions directly from the data or, alternatively, postulate conditions and see if they issue in the data. The former method is the safer, so far as it goes, but it is more difficult and does not carry us so far. The laws of physics are usually stated in the direction from elementary to complex conceptions, and they are not always reversible. Thus, if we are told that a substance is hard and has a grey, metallic lustre, we can deduce only that it is one of several metals or

alloys; but if we find that its atoms have atomic number 26 and have a certain average speed, we know that it is iron, and can deduce its hardness, lustre and other observable characteristics with certainty. Here, then, is the first way in which disagreement can and does arise.

Next, whichever line of attack is adopted, there is the difficulty that the data are not sufficient in themselves to determine the conditions uniquely. If we work from data to conditions, we reach a point where lack of knowledge makes one or more assumptions necessary, and these will be chosen according to the taste of the investigator. If we work from conditions to data, the assumptions must be made at the outset, and their number and character will again depend on the taste of the investigator. It must be remembered in this connection that the stars are not all alike. They differ in brightness, spectrum, mass, density—indeed, in every observable quality, so that the conditions arrived at must be of a sufficiently elastic character to account for all types of stars observed, and, to be convincing, must be such as to show why stars of other types are not observed.

Again, the passage from conditions to data, or *vice versa,* is navigable only by means of abstruse and arduous mathematics. In theory this, being a matter of pure logic, might present difficulty but should leave no ultimate disagreement. In fact, however, disagreement remains. It is to be hoped that time will remove it, but the probability is that, before that happens, fresh discoveries or developments of theory will give the problem a new aspect.

All this excellently illustrates the character of modern astronomical theory, showing on one hand how enormously it has extended its scope since the days when it was a matter of a single postulate, such as the existence of an undiscovered planet, which could be tested by an *ad hoc* observation; and, on the other hand, how intricately it is entangled with the psychology of the astronomer. Those who have been accustomed to rely on the objective, impersonal character of science may deplore this, but a distinction must be carefully noted. Established scientific results are as impersonal as

ever; it is only the methods into which temperament enters, as, in fact, it has always done, though never so obviously as now. Scientific theory is indeed a work of art, supplementing the truth of discovered fact by the beauty of conscious creation.

Although ideas of the internal structure of a star are so unsettled, there is a considerable basis of common agreement which we may briefly summarise. The surface temperatures of at least the great majority of stars range from 2,000 to 20,000 or 30,000 degrees on the centigrade scale. The atmospheric material consists of our familiar atoms, sometimes "ionised" by the loss of one or more electrons, but never more severely handled than atoms which we torture daily in our vacuum tubes.[1] The density in the atmosphere is extremely low. As we go beneath the surface, both temperature and density rise, and the atoms become more and more ionised until, in the neighbourhood of the centre of the star, there is almost, if not quite, complete independence of the nuclei and the surrounding electrons. There is, however, a tendency for atoms to form out of these constituent particles, so that nuclei will be constantly "capturing" electrons. The energy of free motion of a captured electron thus disappears, and simultaneously a "photon" is created—that is, a quantity of radiation which cannot easily be pictured but which for the present purpose we can best regard as a small particle, moving always with the speed of light, whose mass depends on the amount of kinetic energy yielded up by the captured electron. When the photon encounters another nucleus with a captured electron, it liberates the electron, and in so doing passes out of existence. The photons thus act as intermediaries for exchanging energy of motion between the various electrons.

[1] An atom consists of a *nucleus*, which is a compact but unknown association of protons, electrons and neutrons, having on the whole a positive charge, round which revolve, at a comparatively great distance, sufficient satellite electrons to make the whole atom electrically neutral. An atom is *ionised* when one or more of the satellite electrons is removed, and the degree of ionisation increases with increase of temperature.

In the star's interior, this process, with all its implications, summarises the whole duty of the photons. Starting from the centre, where the temperature is higher and their number at any moment is greater than at any other place, we find that their effect is to transfer energy radially outwards, so that the centre is a kind of source of heat for the rest of the star. The farther we go from the centre, the lower is the temperature, the greater is the number of electrons which a nucleus can retain in bondage, and the fewer and less massive are the photons. The process of interchange which goes on is nevertheless of essentially the same character. When we reach the surface, however, there is a change, because many of the photons travelling outwards do not meet with nuclei or electrons, and so escape into space. They constitute the light by which we see the star and from which we have to infer all that we can know about the internal processes.

This constant escape of photons from the surface of a star raises at once the fundamental problem of theoretical astronomy. Where do they come from? They can be traced back to the centre, which, as we have said, acts as a source of heat and consequently of photons for the rest of the star, but how is the central supply maintained in view of the ceaseless radiation from the surface into space? Photons are created when electronic energy is destroyed; hence their loss is equivalent to a loss of such energy—*i.e.*, to a cooling of the star. Nevertheless, there is evidence that the stars remain at approximately the same temperatures for at least thousands of millions of years. The explanation which seems most plausible (though it is not without serious difficulty and is by no means generally accepted) is that photons can be created by the loss, not only of kinetic energy of electrons but of electrons and protons themselves, so that the light which a star sends us is its own essential substance. If this is the true explanation the stars must be gradually passing away, and the Sun, which radiates far less prodigally than the great majority of the stars which we see, is losing four million tons of itself in every second of time. The figure is startling,

but there is ample material in the stars to sustain loss at this rate over the probable period of stellar existence.

The mass of a star is from 10^{27} to 20^{29} tons. Its central temperature is a matter of uncertainty, the lower estimates being of the order of tens of millions of degrees. A comparatively few "giant" stars, however, may have central temperatures lower than this. The average density throughout a star may be anything from that of the highest vacuum we can create to thousands of times that of the densest terrestrial material. The variation of density from surface to centre, however, is probably in all stars tremendous. The extremely high densities, which characterise the white dwarfs, are possible because independent nuclei and electrons can be pressed into much closer association than organised atoms. The space occupied by the solar system, which is analogous to an atom, is great out of all proportion to the actual volume of its material bodies, and the degree of compression which would be possible if the orbits were abandoned suggests the extent to which stellar may surpass terrestrial densities. The average diameter of a star is of the order of a million miles.

A star, as we have seen, may dissipate most of its substance in radiation. There is some likelihood that what remains may pass eternity as an inert mass having the maximum possible density and changing, if at all, only by momentary reversible reactions to the radiation of surrounding unexpired stars. The beginning of stellar life offers a problem to which the answer, if we cannot properly call it more uncertain, is decidedly based on less extensive knowledge. It is customary to contemplate the original state of the universe as that of a finite, uniformly diffused nebula filling all space, but it must be admitted that the justification for this view lies in its harmony with what we like to think of as the course of cosmic evolution rather than in any positive evidence. The phrase, "filling all space," however, does correspond to a definite article of the astronomical creed, according to which a finite quantity of matter can be coextensive with space: in other words, astronomical space,

though it has no boundaries, may be finite in extent and may have a definite volume. It is impossible to picture this, and useless to try. An analogue is the surface of a sphere, over which one may move eternally without reaching a boundary, but which has nevertheless a finite area. This, however, like all analogies, has a strictly limited application, and breaks down if we try to extend it to the inside of the sphere, which has no representative in Nature. A year or two ago the principle of relativity seemed to make infinite space impossible, but a better understanding of its requirements now shows that our present knowledge is insufficient to warrant this conclusion. Some astronomers are, nevertheless, convinced by philosophical arguments for finite space, but scientifically the question remains open.

It is best not to try to visualise finite space. By exercising a strict abstemiousness of imagination we have hitherto accepted infinite space without question, although that too is beyond mental vision. It is scarcely logical to scorn finite space for a quality which its rival equally possesses, and it is not easy to see why there should be a universal instinctive tendency to do so. Possibly it is but one aspect of a general popular revolt against modern scientific concepts which, unlike their predecessors, are in general unpicturable by the imagination. Space, time, energy and the rest of them no longer correspond to the familiar notions we attach to those words, but are pure abstractions, having only a rational significance. We will not now labour this matter, to which we shall return later, but it is well to point out that if the modern scientist takes from the ordinary man (as well as from himself) the power to picture his concepts, he brings as substitute a far more precious gift—namely, the power to express them in terms of something which can be *done*. He displaces contemplation by action; he no longer says, "Look at this," but "Do this," and the new injunction removes the possibility of self-deception which was only too easily realised under the old.

The puzzled reader of modern astronomical paradoxes should therefore ask himself the question: "To what *opera-*

tion does this correspond?" and he can be perfectly sure that his question is capable of an intelligible and usually very simple answer. Let us ask it of finite space, and we shall get the following reply: What is meant by saying that space is finite is that if we travel about in it—taking, if we like, any compass we can devise to guide us always in a straight line—we shall find that if sufficient time is allowed we shall ultimately pass through familiar regions again. There will be a maximum distance to which we can travel from any specified body, such as the Earth, and when we are at that distance, no matter in what direction we move we shall inevitably approach the body, just as any movement from the north pole of the Earth is towards the south pole.[1] This statement of something which can be done is not a *consequence* of the conception of finite space; it *is* the conception of finite space. The question, "Why cannot we travel ever further from the body?" is meaningless for science, for science never asks, "Why?" in such an ultimate way as this. We might as well ask why apples fall to the ground and not away from it: it is not our business to inquire into such things, but merely to record that they do and how they do. The finitude of space, if actual, is a quality of nature, not a metaphysical doctrine.

Whether space is finite or infinite, however, its character is changing. If it is finite the change is accurately describable as "expansion": the sphere we spoke of is like a bladder undergoing inflation, so that points stationary on its surface are getting farther apart. This reveals itself to observation in one of the most remarkable facts of astronomy. It appears that the external galaxies—with very few exceptions, which can be satisfactorily accounted for—are receding from us at speeds proportional to their distances. Nebulæ 43 million parsecs away are retreating at more than 12,000 miles a second, and greater distances, with correspondingly greater speeds,

[1] At present we are not taking into account the expansion of space, which is dealt with later. To make this statement true in an expanding space we must suppose that we are travelling faster than the rate of expansion.

have recently been measured.[1] The material universe is apparently being dissipated, and if the process continues unchecked, the time will come when, however greatly telescopic power may be improved, our own galaxy will be all that we can observe. We shall not lose that also, for the gravitational bond between its stars exceeds the effect of the scattering. It is only bodies at the enormous nebular distances that are bidding us farewell.

If our instinct is to ask, "How can space expand when there is nothing outside for it to expand into?" we must again remember that the idea must be interpreted in terms of operations only. Put somewhat graphically, it means this and nothing more: if we measure the greatest possible distance by which two bodies can be separated, we shall get a certain result; if we perform the same operation tomorrow we shall get a larger result. There is no need to court insanity by trying to imagine expansion into a vacuity which isn't there.

If space is infinite, however, we cannot measure the greatest distance by which two bodies can be separated, for it exceeds all measure. Our operational definition having failed, we must therefore conclude that the thing we are attempting to define is indefinite. We can say either that infinity itself is expanding, carrying its material contents with it, or that those contents are separating in an unchanging space. For mathematical convenience we prefer the former statement, but it has no physical claim to priority. The measurements which are interpreted as recession of the nebulæ are facts, whatever space may be. There is a meaning in saying that space may be finite or infinite, for the alternatives can be distinguished by conceivable observations. But there is no meaning at present in asking if infinite space is expanding or not, because it has no indubitable hall-mark to provide an observable distinction.

[1] The remarks at the beginning of this chapter concerning the meaning of distance and velocity must be recalled here. We need scarcely say that for these measurements very indirect methods are employed.

We cannot leave this point without a warning. Until recently we thought gravitational attraction was a universal characteristic of matter, because it held sway on the earth and among the distant stars. Now that we can examine the remote nebulæ we find that repulsion is the general rule and attraction merely a local peculiarity. In forming our ideas of the universe, therefore, we substitute repulsion for attraction and proceed very much as before. But it would be the height of folly not to learn from our mistake that repulsion also may be merely local, yielding in still more distant space or future time to some other form of interaction. All we say at present about the universe assumes of necessity that the region we observe is typical of the whole. We must morning and evening remind ourselves that that is probably untrue.

This account of modern astronomy, incomplete and unconventional as in many ways it is, has not been drawn up primarily for purposes of instruction. It has been designed to present a bird's-eye view of the movement rather than the present instantaneous state of the moving body of knowledge—a fragment of a cinematograph film rather than a single snapshot. This would seem to be the treatment best adapted to the needs of those who ask such questions as, "What is the meaning of it all?" "What lies behind the revelations of astronomy?" "What will be the effect of recent astronomical discoveries and concepts on our philosophy of the universe?" It is not at all our intention to answer these questions, which everyone must face for himself. They are not scientific questions, although scientific knowledge forms an essential part of the data required in answering them. All we can do by way of a general approach is to clear the ground in order that the questions themselves may stand out in the clearest and most significant relief.

A fact that immediately strikes our attention is that such questions as these, which were commonplace associates of astronomy a century or more ago, are now almost completely divorced therefrom. To give definiteness to the

point, consider the following extract from the preface to a book, famous in its day, entitled *The Practical Astronomer*, by Dr. Thomas Dick. This book, which was published in 1845, is not a popular account of the wonders of the heavens; it is a detailed technical handbook on astronomical instruments, intended for and used by working astronomers in the erection and adjustment of their telescopes and other appliances. This is what the author says: "As this, as well as every other physical subject, forms a part of the arrangements of the Creator throughout the material system—the Author has occasionally taken an opportunity of directing the attention of the reader to the Wisdom and Beneficence of the Great First Cause, and of introducing those moral reflections which naturally flow from the subject."

"Those moral reflections which naturally flow from the subject!" Today no astronomer would use such a phrase in such a connection. A scientific handbook or a scientific paper, as a source of any reflections other than purely scientific ones, is absolutely sterile. Yet there has perhaps never been a time when progress in astronomy has been so provocative of philosophic thought and when so many thinkers have turned to astronomy for light on the fundamental problems of existence. How, then, has this remarkable change come about? It is not sufficient to point to the general secularisation of life and thought, for that secularisation is itself mainly due to the development and dissemination of scientific ideas. We must look deep into the nature of scientific thought before we can find the answer to our question.

I think the answer is at least partly to be found in the fact that scientific investigation appears to have undergone a change of character—though what has actually happened is that our understanding of its character has undergone a change. The older astronomer was inquiring, or thought he was inquiring, immediately into the secrets of creation. The sky spread out before him was the veritable handiwork of a "Great First Cause," a direct revelation of the power of

the Creator Who, however much His character might be misrepresented by mistaken theologians, was there revealed in indubitable terms which none could misconstrue.

"Nous avons changé tout cela." Science today, so far from being a revelation of the Divine, is *contrasted* with revelation as a source of knowledge. We do not now study direct creation so much as the idols of our own conceiving. Where the older astronomer considered a star, we consider "Eddington's model" or an "Emden polytrope." The Universe, of which he spoke with awe, has given place to "the Einstein world" or "the de Sitter world," which is unemotionally thrown on the scrap-heap when "the Lemaître universe" comes into view. If we wish to understand a sunspot we do not face the difficulties which the observations present; we imagine an ideal sunspot from which those difficulties are absent, and study that instead. The solar chromosphere, whose secrets our grandfathers sought to pierce with telescope and spectroscope, has become a "region of monochromatic radiative equilibrium," which we explore with pencil and notebook. And so throughout the whole of theoretical astronomy. The subject-matter of our investigation is not the work of God's fingers but the work of man's imagination.

There is no irreverence in this, nor any betrayal of the ideals of science: it is simply a matter of common sense. One of the first things a young scientist has to learn is to choose his problem to suit the means of investigation at his disposal. An amateur with a 3-inch telescope, who set out to study the structure of the spiral nebulæ, would not be consecrating himself to ultimate Truth; he would be acting like a fool, wasting on an impossible problem time which might be spent with profit on, say, observations of variable stars. The modern theoretical astronomer has learnt this lesson. His most powerful instrument is mathematics, and he therefore chooses for his study problems which can be dealt with mathematically—more specifically, those problems which can be dealt with at our present stage of attainment in mathematics. A star as nature reveals it to us is too

intricate for this, so he imagines a gaseous sphere to which he assigns certain mathematically tractable properties, and works out the brightness, density and other observable qualities which such a sphere, if it existed, would have. If those qualities approximate to those which are actually observed in the stars, the presumption is that his sphere is an approximate representation of a star, and the degree and character of its shortcoming guide him in making the representation more exact.

There is, of course, an insidious danger in this. We are liable, particularly at periods when our models are unusually successful in copying nature, to think that they actually are nature. This tendency must be carefully guarded against. We have no right to assume that nature, by a self-denying ordinance, has limited her phenomena to those which can be described by mathematical processes; still less legitimately can we say that nature, or God, must be fundamentally mathematical because, in studying the physical world, we voluntarily restrict ourselves to mathematical conceptions.

It is necessary to point out this danger, but in truth it is not a serious menace to the astronomer; the scientific philosopher is its most likely victim. The astronomer devotes himself confidently to his models and abstractions, not because he thinks them reality but because he sees that not only they, but also the apparently concrete subject-matter of his predecessors, are essentially abstract; that, in fact, physical conceptions for the past 300 years have been only nominally identical with the actual experiences with which they have been associated. The modern attitude of science to observation is not a departure from tradition but the unrestricted exercise of a liberty which past generations have possessed and to some extent employed without realising it. Let us examine one or two of the well-known scientific conceptions prominent in astronomy in order to illustrate this general truth.

One of the most important conceptions of astronomy is that of *force*, by means of which Newton was able to make

the great generalisation of universal gravitation. Now force is a familiar experience, represented, for instance, by the pushing of one object against another. Newtonian force, however, has nothing to do with pushing or pulling; it is defined simply as that which causes a change in the motion of a body. If a body is accelerated, Newtonian mechanics says that a force is acting on it. A naïve student might look to see if this is actually so, thinking that perhaps Newton's ideas might have been incomplete and that something else besides force is capable of changing motion. Such an inquiry would be perfectly legitimate, and indeed an obvious one to make, if by "force" Newton meant the everyday thing which countless generations before him had meant by the word. What makes it absurd is that Newton meant something essentially different from this. His force was *defined* as the cause of change of motion. Whatever caused such a change, whether it was a push or a pull or any other agency, was to be called a force, and the whole character and measure of the force were embodied in the change of motion.[1] The scientific conception of force for the last 250 years has been that of Newton, but the interpretation of scientific statements has usually been in terms of physical sensations.

Another example is afforded by the conception of a *gas*. What we mean by a gas according to ordinary observation is something tenuous, at least partly transparent, spreading out to fill whatever space is available for it, a medium through which bodies can move with considerable freedom. The "gaseous" bodies with which the astronomer deals, however, may be far denser than lead, opaque even to hard X-rays, exceedingly compact, and as sticky as treacle. The explanation of the paradox is that the astronomer's "gas"

[1] Even the notion of *cause* is not inherent in the Newtonian definition. It is actually more accurate to drop this anthropomorphism and simply to say that Newtonian force *is* the change of motion. Newton's second law says that force *equals* rate of change of motion. "Cause" is introduced merely to make the process picturable. The idea is not used in science, and it is even sometimes more vivid (as in the example of centrifugal force) to regard the change of motion as causing the force.

is not defined in terms of observation. It is simply a substance composed of hypothetical unit particles whose average distance apart is considerably greater than their diameter. Yet we have spoken indiscriminately of this substance and of air as "gases." It is necessary to realise that the single, common name is justified only if by gas we cease to mean the substance corresponding to certain familiar sensations. Like force, it is a name long since used in science only as denoting an abstract idea.

Examples might be multiplied *ad lib.* The model of the universe which astronomy has been building up since the time of Galileo is an ideal one, constructed of bricks made from rational conceptions, not from sensible experiences. The open acknowledgment of this fact, made during the last decade or so, is the result not of a revolution in method but of a clearer understanding of what has been done in the past and a greater freedom in employing conceptions which have no obvious analogues in experience. The exercise of this freedom is the source of much of the difficulty met with in trying to understand recent developments.

It must be admitted, however, that the confusion arising from this discrepancy between the direct mental representation of immediate experience and the more abstract conceptions of science (which, in its general form, is simply the familiar confusion of calling different ideas by the same name) is not peculiar to the layman. For the scientist also there are dangers in the gradual change of significance of an idea with increasing abstraction, in that earlier and later stages in the development of a conception may be unwittingly regarded as identical because they bear a common name. There is an interesting situation at the present time which possibly exemplifies this; namely, the inconsistency, already referred to, between the implications of different definitions of time. One line of thought in which time is involved gives our stellar system an age of something like 10^{13} years. Another line of thought makes the whole universe much younger than this. The task of tracing back the

intricate lines of argument to see precisely what is meant by "time" in each case is an extremely difficult one, but it may have to be undertaken. The only thing which is clear now is that unless the universe is fundamentally irrational, different definitions have been used—and it may be added that neither of them corresponds in all respects with our usual notion of time. The reconciliation of the results may have wide implications.

We are, then, to regard as the most significant feature of modern astronomy the realisation which it brings of the nature of astronomical conceptions. We see that those conceptions, which have in the past been identified with experiences drawn directly from our contact with the external world, are in reality creations of our mind, whose function is to correlate our various observations and so make the world rational—in other words, to make a rational *universe* out of diverse phenomena. In the limited field of observation open to us in the past, the differences between scientific conceptions and the corresponding familiar notions have been inconspicuous, so that their existence has been widely overlooked. The great extension of observational astronomy in the last few decades, however, has made fresh demands on the conceptions, in fulfilling which their divergences from familiar notions have been glaringly exposed. What we thought were direct revelations of nature we find to be our own inventions—not arbitrary inventions, it is true, for we choose them in order to give coherence to facts given us in observation, but nevertheless inventions which further experience may force us to modify perhaps beyond recognition. We thought them facts which were eternal, and we find them ideas which are transient, or at least protean.

These considerations, which will be extremely disconcerting to those who expect to find in astronomy an immediate revelation of a wonderful and unique universe, are presented without apology, for they represent actually what astronomy is concerned with today. The change, compared with the aspect of astronomy in former times, is great, although, as we have said, it is only skin-deep. But it will be objected:

"You have spoken only of theoretical astronomy, of our *interpretation* of the facts; what of the facts themselves, revealed to us by direct observation? Are they not being discovered now as formerly, and do not they reveal to us something not ourselves which speaks of a Power behind nature?" True, observational astronomy is not languishing. It is the source and has the control of all our theories, and it is being prosecuted today with a vigour and on a scale undreamed of a hundred years ago. But alas! it is no longer the observation our great-grandfathers knew; it is something which itself depends scarcely less on interpretation than the theories which it originates. When Herschel discovered the planet Uranus he saw its surface with his own eyes, and observed its movement among the fixed stars. Pluto was discovered by the change of position of a spot on successive photographic plates taken as the result of mathematical calculations made many years ago. Halley discovered the movement of the stars by observing directly that their positions in the sky were no longer those observed 1,800 years previously. We discover the movement of a spiral nebula by measuring the positions of marks on a tiny rectangular smudge on a single photographic plate. Almost the whole of observational astronomy today consists of marks on photographic plates which are quite unintelligible to the uninitiated, and require the application of physical theory before they become the data used by the theoretical astronomer. All that can be discovered by direct observation is already known.

And so we see why astronomers no longer discourse of "those moral reflections which naturally flow from the subject." They are too modest. They realise that whatever grandeur belongs to the universe they picture is a grandeur of their own creating, and they hesitate to proclaim it. Doubtless they are right in this, for otherwise they could hardly avoid misunderstanding. But at the same time, from a thoroughly impersonal point of view it would perhaps appear that there is no less cause than formerly for reflection on the meaning of scientific progress. If modern astronomy

reveals to us more of the nature of our minds than of the external world, is the exchange so much to be deplored? For it is not the arbitrary, capricious, personal elements of our minds that are embodied in astronomy; they can be left to psycho-analysis to do with them what it can. Astronomy absorbs the universal, impersonal factors which form the substratum of mental life. The universe we contemplate today may disappear tomorrow, but it represents a mental *nexus* between the diverse facts of present experience which is not the whim of a single astronomer, but one of a few alternatives forced on all by the nature of logical thought. That is surely not without meaning.

The scientist is sometimes regarded, in contrast with the poet, as a dull, mechanical being, who looks at nature without emotion and sees only dead logic in the living garment of God. "When I heard the learn'd astronomer," wrote Whitman, "how soon, unaccountable, I became tired and sick; till, rising and gliding out, I wander'd off by myself in the mystical, moist night-air, and from time to time look'd up in perfect silence at the stars." But in truth it is a shallow nature which can draw emotion from the skies at will as one draws water from a fountain, and the experience has little ultimate value. The astronomer in his nightly or daily work is not as a rule entranced with the wonder of things. He regards the stars in the matter-of-fact way which is essential to the proper performance of his work, and is no more overcome with rapture than is a surgeon with pity. But to him, as to others, there come rare moments when the familiar suddenly and imperceptibly takes on an unfamiliar appearance, when thought becomes strangely clear, and the finite seems to open out into the infinite. It may be that such moments come less frequently to the astronomer than to those who have no scientific interest in the sky, but can it be doubted that when they do come their content is greater and their value deeper and more lasting from the knowledge, felt rather than thought, that the universe is no chaos but that all its diverse elements are bound together into an ordered whole by the stuff of which man's mind is made?

MATHEMATICS: QUANTITY AND ORDER

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THE extent of general intellectual interest in mathematics has varied in different periods of human thought. It has always been acknowledged that mathematics is of basic importance because of its applications. But whether it is to be regarded merely as the useful handmaid of the sciences or as the queen of the sciences has been a matter of considerable dispute. On the one hand, we find the common 'practical' attitude of which Newton complained to Halley in a letter of 1686:

"Now is not this very fine? Mathematicians that find out, settle, and do all the business must content themselves with being nothing but dry calculators and drudges; and another that does nothing but pretend and grasp at all things must carry away all the invention. . . ."

On the other hand, there is the feeling of Pythagoras, Plato, Descartes and other lofty spirits that somehow mathematical thought furnishes the master-key to philosophic insight.

The advent of the present century ended a period in which the range of both pure and applied mathematics had been enormously extended. Thus in his *History of European Thought in the Nineteenth Century* Merz concluded that progress in the several fields of science had been more or less proportionate to the extent to which mathematical methods had been introduced: ". . . through the increasing applications of mathematical methods of measuring and calculating, our thought has become truly scientific. . . ." Nevertheless, the general attitude was one which conceded a fundamental practical value to mathematics rather than one which admired

its beauty and profound significance. This fact was evidenced by contrast. An astronomical, physical, chemical, or biological discovery was hailed, not only by the specialist, but by the philosopher, the theologian, and intelligent layman as well, for all felt that new insight of first importance was thereby gained. But such an epoch-making mathematical discovery as that of the transfinite numbers of Georg Cantor, which would doubtless have been appreciated to the full by the ancient Greeks, remained for a long time unnoticed even by the philosophers.

Today, however, the situation is strikingly different. It is generally felt that mathematical thought possesses a fundamental significance not yet wholly understood, and Plato's mystic conjecture that the Deity 'geometrizes continually' is repeated in new forms by Jeans and others.

The principal factors which have led to this revival of interest are easy to trace. Of dominant importance has been the formulation of Einstein's special or electromagnetic theory of relativity of 1906, and of his general or gravitational theory of 1915. Both broke in rudely upon a previously almost unquestioned dogma of human thought—namely, that of absolute simultaneity and absolute time.

The effect thereby produced can scarcely be over-estimated. It had been the fondest hope of the mechanistic physics to show that the physical world was in essence only a puppet-show of a very particular kind—namely, one in which the puppets were 'rigid elastic spheres' and similar idealized objects, held together by idealized 'weightless springs,' while the stage was to be that of Euclidean space and absolute time. And now the relativistic theories demanded a new stage on which these time-worn puppets could not even appear. Thus the new theories upset those of classical physics completely, as far as any hope was concerned of furnishing a final picture of physical law, although the approximate truth of the old formulations was not affected, of course.

The theories of relativity were predominantly mathematical in that their adequate comprehension involved the well-known geometric theory of Riemann concerning geo-

metrical spaces of *n* dimensions and the absolute differential calculus of Ricci and Levi-Civita—both purely mathematical theories. In fact, the fundamental idea of the gravitational theory of relativity undoubtedly occurred to Einstein in the form of a mathematical question: "Might not the paths of particles (planets or light-beams) about the sun be merely the shortest paths in a semi-flat, four-dimensional Riemannian space-time?" And in order to answer this question Einstein found it necessary to learn and apply the fundamental technique of the absolute differential calculus. The numerical result of his calculation supported the correctness of the conjecture.

Thus it is certainly not exaggerating the case to say that, without the purely mathematical ideas of Riemann, Ricci, and Levi-Civita, neither the special nor the general theory of relativity could have taken form.

Physicists and astronomers have not always been as fortunate as Einstein in finding mathematical theories ready made for their needs. Kepler had sound ideas about the rôle of gravitational force in the solar system, but he lacked the necessary mathematical tools to develop them—namely, the analytic geometry of Descartes and the infinitesimal calculus of Newton and Leibnitz. Newton himself had to invent the calculus in order to be able to work out the consequences of the suspected gravitational law. Faraday's experimental genius required to be supplemented by the mathematical genius of Maxwell and Hertz before the full consequences of Faraday's work could be seen; and it is by this curious path that the 'radio' has come into existence.

Since 1915 the mathematical demands upon the physicist have been constantly increasing through a succession of "mathematical theories" which, Bridgman says, "are being continually formulated at an ever-increasing tempo and in a complexity and abstractness increasingly formidable." No one doubts that these theories of Bohr, de Broglie, Schrödinger, Heisenberg, and Dirac are of the utmost significance, but the predominant rôle of purely mathematical framework is apparent. As Dirac has phrased it:

". . . Mathematics is the tool specially suited for dealing with abstract concepts of any kind, and there is no limit to its power in this field. For this reason a book on the new physics, if not purely descriptive of experimental results, must be essentially mathematical.

". . . *The only object of theoretical physics is to calculate results that can be compared with experiment,* and it is quite unnecessary that any satisfying description of the whole course of the phenomenon should be given."

Thus purely mathematical processes have taken a position of central importance, leaving the average physicist, however, in a very uncertain frame of mind.

As an indication of this situation, I recall a series of five lectures given within a few years by a distinguished physicist, in which he proposed to expound his new theory. What was my surprise to find *nothing* but classical mathematics presented in the lectures, dressed up, it is true, in an alluring garb of physical terminology. As far as I could observe, my somewhat bewildered friends the physicists were entirely satisfied. Of course, this was because they were eager to gain an appreciation of the mathematical processes which mysteriously ground out the right answers at the end.

A possible danger is that, with the infinitely varied resources of modern mathematics at the disposal of the theorist in physics, and with no specific limits set to his hypotheses, he can always devise an *ad hoc* mathematical machine which will do whatever is required. But this danger, if such it be, is altogether outweighed by the advantages of ceaseless and daring mathematical formulations which aim to explain and predict in the weird domain of atomic physics.

Thus the aggregate effect of recent advances in physics has been to bring about the general conviction that the understanding of final law in the physical universe will turn out to be a mathematical understanding rather than one in which ordinary physical concepts and intuitions play the chief rôle.

Of this truth the mathematician hardly requires to be convinced. He may be compared to the mining geologist, who is primarily interested in important mineral deposits,

wherever they may exist, and who cannot think even of sea water without realization of its mineral content. Likewise the mathematician, these many centuries, has been searching for *logical structure* and finding it everywhere. All physical phenomena suggest to him 'differential equations' or other equations which embody their fundamental quantitative laws. But, equally, all biological, psychological, and social phenomena seem to him to reveal logical structure, however rudimentary in character, and he must believe that deeper progress in these more difficult directions can only be realized when suitable mathematical concepts and methods have been devised. Furthermore, the vast domain of purely mathematical thought forms for him irrefutable testimony that the subjective as well as the objective world is mathematical. Thus with Descartes he will declare *Omnia apud me mathematica fiunt*—With me everything turns into mathematics.

While recent physical advance has been the principal reason for the renewed interest in mathematics, another cause of less importance from the practical point of view, but perhaps equally significant at bottom, must be mentioned. The philosophers, who long regarded logic as part of their especial domain, realize today that logic is coextensive with mathematics; for, according to the American mathematician Benjamin Peirce, "mathematics is the science which draws necessary conclusions." It might appear that rigorous deductions could be found in non-mathematical domains. George Boole, the Irish mathematician, tells us, however, that, in trying to find an example of a syllogistic chain of reasoning (not of the obvious Aristotelian type) to illustrate his symbolic logic, he searched in vain through the work of that most mathematically minded of philosophers, Spinoza.

Thus mathematics is the codified body of *all* logical thought.

. . . . .

What is the inner secret of mathematical power? Briefly stated, it is that mathematics discloses the skeletal outlines of all closely articulated relational systems. For this purpose

mathematics uses the language of pure logic with its score or so of symbolic words, which, in its important forms of expression, enables the mind to comprehend systems of relations otherwise completely beyond its power. These forms are creative discoveries which, once made, remain permanently at our disposal. By means of them the scientific imagination is enabled to penetrate ever more deeply into the rationale of the universe about us.

There has been a fundamental effort on the part of those interested in symbolic logic to give it a purely mechanical form. This has been a natural aim suggested by the pioneer work of Boole on that subject, in which he shows that symbolic logic is *a kind of algebra in which the only two symbols of quantity are* 0 *and* 1.

Thus it has been sought to make logical reasoning as definite and precise in its rules of manipulation as the game of chess, with which it may be compared as follows: The assumed propositions or hypotheses correspond to a given initial 'position' of the chessmen; the 'moves' are then the ones allowed in the logical game in passing to other more complicated propositions, and the game is won when the desired final proposition is arrived at in this manner.

Unfortunately, this alluring goal of logical mechanization has not yet been effectively reached. Indeed, in chess itself there are moments when the arbitrary inaccurate judgment of an umpire is required to determine whether or not a move has been initiated or not, whether a time limit has been exceeded, or whether a game is a draw; and it is even conceivable, although entirely unlikely, that some possibility not foreseen by the rules of chess might arise. In symbolic logic much more formidable difficulties exist which stand in the way of its effective reduction to a genuinely mechanical game. There are three of these difficulties to which I will refer briefly.

The first is occasioned by the fact that the meaning of a logical statement is not entirely independent of what precedes it; in chess, on the contrary, a player can continue the game from a specified position without any regard whatsoever to

what has taken place earlier. If this dependence of logical meaning upon what has gone before is ignored, queer logical paradoxes result; for example, the following well-known one.

All integers admit of being defined in a finite number of words (of the English language). We may name the *least integer not definable in less than one hundred English words.* This is a perfectly definite integer, since there are only a finite number of combinations of less than one hundred words. But it has just been defined in only eleven words!

The inherent difficulty may be elucidated as follows. For definiteness let us select some particular dictionary in which, of course, certain integers, as one, two, . . . thousand, million, etc., appear as words. These are definable in two words, such as the *integer three,* for instance. Thence we proceed, step by step, to collections of three, four, and more words, striking out those collections which are not satisfactory English definitions of an integer. Theoretically—at the end of many, many æons!—all the combinations of less than one hundred words will have been used up, and a certain extremely numerous set of integers will have been defined. We then proceed to list these numbers in order of magnitude—

$$1, 2, 3, \ldots$$

and we observe the first gap in the series. This occurs at the least integer not definable in less than one hundred words.

But with this series in mind as already obtained, only eleven words are necessary to define this interesting number! And this same sequence of words will have been rejected earlier as not furnishing a satisfactory definition!

The obvious conclusion is that the meaning of a logical statement may depend vitally upon what has gone before. If this fact be ignored, all sorts of logical confusion are certain to arise.

The theory of the 'hierarchy of types' in symbolic logic was designed by Russell and Whitehead precisely in order to eliminate this dangerous source of confusion and contradiction. It has been largely successful in doing so, but since, as each successive logical type is defined, an independent new

logical act is required, the logical theory so obtained can hardly be regarded as a purely mechanical one.

There is also a difficulty in disposing of the following question: "How far is choice by 'fiat' allowable as against choice by 'definition'?" If, for instance, I say, "Let an arbitrary correspondence be set up such that to any integer there is a corresponding unique prime integer," I am proceeding by 'fiat,' and I have no logical qualms in this case; for have I not an infinitude of prime integers to draw on—namely, 2, 3, 5, 7, 11, 13, . . . and can I not take them arbitrarily one at a time to correspond to the successive integers? But there is no necessity for proceeding by fiat in this case, for I can make the nth prime in order correspond by 'definition' to the nth integer as follows:

$$1 \rightarrow 2,\ 2 \rightarrow 3,\ 3 \rightarrow 5,\ 4 \rightarrow 7,\ 5 \rightarrow 11,\ \ldots .$$

Now in more complicated cases the second way of choice by definition is not open. For instance, if I consider all (finite or infinite) collections of numbers between 0 and 1—*i.e.*, all sets of numbers like 0·361785 . . . where the figures 3, 6 . . . are taken arbitrarily, I can by *fiat* select one representative number out of each one of this colossally infinite set of collections—but I can never do so by *definition*!

Evidently the act of choice by means of explicit definition is much more realistic than that made only by fiat, and it is found that there exist remote domains of mathematical thought which are valid or not according as we allow choice by fiat or require choice by means of a constructive definition.

Thus those esoteric parts of mathematics in which extremely elaborate choices enter are still in a state of much vagueness. Fortunately, however, if we remain in the ordinary domains of mathematics, these difficulties never enter, since choice by definition always suffices.

Here, then, is a difficulty in symbolic logic as to the extent of allowable choice, on which opinions of competent mathematicians actually differ.

A third difficulty is one concerned with the nature of the integers, considered from the purely logical point of view.

Russell and Whitehead, following the German mathematician Frege, would make of the integer and so of all numbers a logical 'construct' based upon the logical relation of one-to-one correspondence of classes. How natural this attempt is appears from the fact that numerically equal classes are precisely those which may be matched in one-to-one correspondence. Thus I can make each finger of my right hand touch the corresponding finger of my left hand, because there are five fingers in each hand.

Unfortunately, the notion of the integers is so deeply intrenched in our very use of the symbols of logic that it is not clear whether number may safely be regarded as a purely logical 'construct.' The great German mathematician Hilbert takes in the integers as a basic part of his logic, and thus avoids a possible vicious circle.

It will be seen that these difficulties, referring to the frontiers of symbolic logic, do not threaten the validity of the main body of accepted mathematical thought. Whatever the final outcome, nothing is to be anticipated which will affect the principal syllogistic chains thus far discovered, although certain remote types of 'transfinite reasoning' may be imperilled.

As might be expected, however, in this day when every dogma is questioned, there have been attempts to detach logic from its apparently secure position. Since we have been able to invent non-Euclidean geometries, and to unite space and time, why should we not invent non-Aristotelian systems of logic quite as interesting and self-consistent as Aristotelian logic?

It was the Dutch mathematician Brouwer who first proposed a system of 'intuitionist logic,' in which a proposition may be true, or false, or *neither true nor false*, thus denying the accepted principle of *tertium non datur*.

Now it is conceivable that some mathematical facts may not be demonstrable. For instance, it is exceedingly probable that, in the well-known number

$$\pi = 3{\cdot}1415926\ldots,$$

the sum of the first n figures divided by n tends to approach 4·5 (the average of the ten digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9). For why should not there occur in the long run approximately as many of each of the ten digits? In fact, if we compute the average of the first twenty-five digits occurring, we obtain 4·72, which differs from 4·5 by less than 5 per cent.

But in the present state of mathematical science no one knows of any method for proving that the average does tend actually towards 4·5. If this conjecture should be true, but not demonstrable, we could never be certain of the fact by means of any computation of the successive averages, however extensive, since there might exist an unexpected distribution of the later digits.

There are two attitudes which might be taken in this event:

(1) The asserted law of averages is regarded as true though not demonstrable.

(2) The asserted law of averages is regarded as neither true nor false.

If we adopt the second point of view, which is Brouwer's, we are, in my opinion, adopting an unnatural form of expression which puts mathematics into a kind of straitjacket, and renders it less attractive; and, furthermore, we are not thereby bringing out essentially new facts.

After all, mathematics consists in the discovery and clear codification of genuine and important syllogistic chains of reasoning. Any scrupulously honest result in this direction can be depended upon to have permanent value, even although a more precise form of statement may be discovered later on. In this connection I am reminded of a mathematical paraphrase once used by the American mathematician E. H. Moore: "Sufficient unto the day is the precision thereof." The final day of maximum precision of logical thought has not yet arrived, and that day may be long delayed. By what peculiar means such precision is to be attained cannot be forecast in advance. Suppose that I assert that my friend A was in England on a certain day. As far as this assertion is concerned, he might have been just entering England over

the Scottish border at midnight of that day. However, if I assert A was in England on a certain date, and *in fact was in Cambridge at noon of that day*, the precision of my first assertion is made absolute by means of another assertion which in itself is not wholly precise! Likewise it may turn out that the ultimate form of symbolic logic will carry with it the use of auxiliary propositions whose truth or falsity is not wholly clear. Perhaps, in some such sense as this, there may be a certain kind of validity in Brouwer's affirmation that a proposition may be neither true nor false.

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It has been remarked above that the forms of mathematical expression—and in particular its special symbolisms—must be regarded as discoveries of fundamental importance; the alphabet is a symbolic discovery of similar type whose importance likewise cannot be over-estimated. In general the chief function of mathematical symbolism is to enable the human mind to carry through certain processes of logical thought.

While the mind in its logical workings starts from a few extremely simple ideas corresponding to the terms of the primitive logical language, it is soon found that certain natural groups of these ideas and terms constantly reoccur. Thus, with or without the intervention of special creative ingenuity, there arises the habit of treating such groups as a unit and of naming them by special symbols.

This process is strikingly analogous to that by which atoms are formed by the natural aggregation of protons and electrons, or crystalline structures out of atoms. Here we may revert once more to our mineralogical analogy and compare the varied natural forms of logical structure to the crystalline forms of mineral structure.

It is in this way that the numbers—the most important special symbols of mathematics—inevitably arise. The main phases are as follows: (1) The use of special marks (integers) instead of counters, for convenience in counting; as, for instance, the use of one large stone instead of ten small ones, in

counting a herd of animals; (2) the use of special marks and positions to indicate addition, subtraction, etc.; (3) the codification of general laws, using algebraic marks (letters) to stand for any number, thus leading successively to the fractions, zero, the negative numbers, and finally the so-called imaginary numbers involving the symbol $\sqrt{-1}$; (4) the observation that the process of extension terminates naturally at this stage. The full justification of the complete number system under the general laws of operation can be made without much difficulty, so that to any person with a fair mathematical training the term 'imaginary' seems a misnomer when applied to the so-called imaginary numbers. The simplest means of making such a justification is by means of a geometrical representation of these numbers and the operations to which they are subject.

A particularly simple illustration of this general evolutionary process is the following: The algebraists were in the habit of writing *a quadratus* for the square of *a*, with like expression for the cube of *a*, etc. Then for brevity they jotted down a^2 or a^3 instead, or similar expressions, putting the 2 or 3 in special position to indicate that it was not a factor but a power. In this way they passed insensibly from obvious special laws such as

$$a^2 \times a^3 = a^5$$

to the corresponding general laws such as

$$a^m \times a^n = a^{m+n}.$$

But this suggested automatically the question as to what a^0, a^{-1}, . . . represent, and also the inevitable answers; for evidently we have $a^2 = aa$, $a^1 = a$, $a^0 = 1$, $a^{-1} = 1 \div a$, etc., when we divide by a successively. In the same way the query as to the meaning of $a^{\frac{1}{2}}$ arises. But by the above law the following equation must hold:

$$a^{\frac{1}{2}} \times a^{\frac{1}{2}} = a^{\frac{1}{2}+\frac{1}{2}} = a^1 = a,$$

whence it was concluded that $a^{\frac{1}{2}}$ *must be* the square root of a.

This is a typical instance of the characteristic natural pro-

cess at work in the elaboration of symbolic forms: the meaning of apparently meaningless combinations of symbols is sought in the light of the known formal laws of manipulation.

From the practical point of view the importance of a thorough exploitation of the formal domain is obvious. Only by complete mastery of it are we able to provide the varied symbolic forms which are required in applied mathematics.

At this point it is desirable to recall why the notion of 'function' is a most important one in the applications of mathematics, and also to point out that this notion is inherent in the formal domain of number just referred to, without regard to any such applications.

If x is a generic symbol for a number that may have any value, then x is called a 'variable.' Now it may happen that a second variable y is determined when x is given. For instance, the distance, y, which a body falls from rest in a vacuum depends on the time elapsed, x; in fact, we have the functional relation $y=16x^2$ very nearly, if x and y are measured in seconds and feet respectively. In this case y is said to be a 'function' of x.

It is obvious that mutually dependent physical variables are found everywhere in nature, so that the notion of function is fundamental in the applications of mathematics. But it is also easy to justify our assertion that the notion of function arises naturally, regardless of any application. For example, we know, by ordinary 'long division,' that

$$\frac{1}{9}=\cdot 11111 \ldots$$

$$=\frac{1}{10}+\frac{1}{100}+\frac{1}{1000}+ \ldots \textit{ ad inf.}$$

But since there is no especial virtue in the base 10 of our decimal system as against any other base x, we conjecture and prove that *in general*

$$\frac{1}{x-1}=\frac{1}{x}+\frac{1}{x^2}+\frac{1}{x^3} \ldots$$

In other words, we find it desirable to introduce variables in order to express a general truth, rather than arbitrary special manifestations of it. This explains why the language of functions is the natural one in dealing with the domain of number.

The vast array of general relationships of the above type is called *analysis* by mathematicians, and constitutes one of the major divisions of pure mathematics, along with geometry, algebra, and arithmetic; it will be understood, of course, that these terms are to be interpreted in an extremely broad sense. No one of these divisions in its full extent can be traversed by any single mind!

If one asks what these numbers and other similar symbols *really* are—as, for instance, what *is* the number 2—only one answer can be given: Such symbols are the abstract marks representing specific collections of other symbols or things. Thus the number 2 is a special mark which designates the class of the letters A, B, or any other class in one-to-one correspondence with it (as C, D, or the sun and moon). Our strong feeling that the number 2 *exists* springs from the fact that we can operate with the mark 2 much as we do with any other objective thing because its properties are absolutely clear and permanent.

There are other kinds of marks besides those of the ordinary real or imaginary numbers which the mathematician considers as 'numbers'—for instance, 'hypercomplex numbers,' 'modular numbers,' 'ideal numbers,' and the 'transfinite numbers' of Cantor. Such symbols are considered to be numbers because they satisfy nearly all of the requirements obeyed by ordinary numbers.

Concerning the first three types of numbers mentioned it may be remarked here that it is possible to represent such numbers explicitly in terms of ordinary real numbers, just as the ordinary imaginary numbers can be so represented. Furthermore, these three types of numbers have many important applications. In fact, the 'matrices' of the recent physical theories of Heisenberg and Jordan are essentially hypercomplex numbers. For these number systems the 'commuta-

tive law of multiplication' $ab = ba$ fails to be generally true, but all the other laws hold.

The fourth transfinite type of number is the most interesting of all from a philosophic point of view. These arise as follows: The integers are the marks for finite classes; for a long time the mark ∞ has been applied to classes possessing an infinite number of objects, such, for instance, as the class of all integers 1, 2, 3, etc. Thus the marks or numbers attached to discrete classes have been

$$1, 2, 3, \ldots \text{ and } \infty.$$

Now Cantor observed that some infinite classes are really *more* infinite than others. The test for equality of infinities is naturally the fundamental test of one-to-one correspondence; thus there are as many even integers as there are integers, as the following one-to-one correspondence shows:

$$\begin{array}{l} 1, 2, 3, 4 \ldots \textit{ad inf.}, \\ 2, 4, 6, 8 \ldots \textit{ad inf.}, \end{array}$$

in which each integer is made to correspond to its double. Likewise it may be proved that, contrary to first expectation, there are as many fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{2}{3}$, $\frac{1}{5}$, etc., as there are integers. This kind of infinity is called a 'countable infinity.'

More specifically, Cantor proved that the aggregate of all positive numbers less than 1 forms a larger *uncountable* infinity, and his proof is almost instantaneous. If all the numbers between 0 and 1 could be counted off in order—that is, written in a countable succession, as *a*, *b*, *c*, etc.—we would reach a contradiction as follows: Form a decimal sequence of digits whose first figure after the decimal point differs from that of *a*, whose second figure differs from that of *b*, and so on indefinitely. This stands for a number less than 1 and not equal to any in the sequence *a*, *b*, *c* . . . since its digits are not all the same as those of *a*, or of *b*, or of *c*, etc. Hence not *all* of the numbers can be listed in such a countable sequence *a*, *b*, *c*, . . .

Thus infinite classes may be classified according to their degree of infinitude, and assigned corresponding marks, the

so-called transfinite cardinal numbers, of which the countable infinity is the least. However, only a countable set of these transfinite cardinals can be assigned definite marks, since only a countable set of marks is at our disposal. The similar transfinite ordinal numbers of Cantor play a fundamental part in the theory of logical types of Russell and Whitehead.

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When we observe any class of phenomena, certain 'undefined elements' are in general found to be significant, as well as certain 'undefined relations' between these elements. These elements and relations are left undefined because we cannot define all our terms without involving a vicious circle, and so there must always remain a certain set of elements and relations which are taken for granted.

As soon as the 'postulates' or fundamental laws involving these elements and relations are known we feel that we understand the phenomena in question. In particular we expect to be able, with the aid of mathematical reasoning, to deduce all further facts and to make any desired predictions. The mathematical body which results is called an abstraction.

The number system itself affords a very important instance of an abstraction. Here the elements are numbers; the relations are those of equality, etc., while the postulates are such laws as $a+b=b+a$, etc. Likewise the geometry of Euclid, with points and lines for undefined elements, with various undefined relations such as that a point lies on a line, and with postulates such as the 'parallel postulate,' forms an abstraction.

The creative mathematician is very skilful in the modification of abstractions. Thus from Euclidean geometry he has passed to the more general non-Euclidean geometries by omission of the parallel postulate, and similarly he has devised other kinds of geometry. In the same way he has invented various number systems of much interest and importance, as has been pointed out above. The prototypes of the abstractions of mathematics are suggested by everyday

experience and by the various domains of experimental science.

An instructive instance of how abstractions may arise in the most unexpected manner is the following. According to the Constitution of the United States of America, each state is entitled to a number of Representatives in Congress (at least one) proportional to its population, the total number of Representatives being determined by law. But this constitutional requirement cannot be carried out exactly, of course. The question, then, arises as to how it can be carried out with least injustice to any of the states. Thus there begin to arise 'elements': the conceivable populations of the states together with possible assignments of representatives. Furthermore, of two elements with the same populations but different assignments one is to be thought of more just than the other —a 'relation' between two elements. Finally, there are certain natural postulates which present themselves, as, for instance, the following: In the best possible assignments for given populations of the states the larger of two states should receive at least as many representatives as the smaller. Thus by a careful analysis, which cannot even be indicated here, my colleague Professor Huntington has succeeded in determining the 'best' method of assigning representatives in any case whatsoever (that designated by him as the method of the 'harmonic mean'), and he has compared it with other rival methods, including the one in actual use.

His primary contribution seems to me, however, that he has shown how, in the difficult social domain, the choice between different conclusions may hinge upon a slight difference in sets of underlying postulates, both of which appear equally reasonable or nearly so. From this simple illustration it is suggested that mathematical abstractions may prove of vital importance at the social level, where their chief rôle is likely to be one of clarification and classification.

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Pythagoras first made the conjecture that the physical world is governed by mathematical law. In this way he fore-

saw a fundamental truth which innumerable researches in the physical sciences since his day have established in detail. His starting-point was given by a few simple laws obeyed by musical strings, and by the earth, sun, and planets; but these were sufficient to lead him to a conclusion which lay far beyond the vision of his contemporaries. Such moments of insight justify our utmost efforts to obtain as wide a philosophic outlook as possible.

At the present time we are confronted with innumerable known facts codified in many important laws, and more and more of these are continually being accumulated. No one mind can hope to grasp the immense array. We are overwhelmed by an avalanche of increasing knowledge, and it is essential for the welfare of our spirit that we obtain a better understanding of the nature of knowledge, just as it was imperative in the time of Pythagoras that the human spirit should gain some appreciation of the ordered regularity of Nature.

This quest for deeper understanding is a difficult one, of course. It is part of the purpose of these essays that specialists in diverse fields of science should express themselves in what may be called the Pythagorean manner in so far as they feel justified in doing so. In order to share in the fulfilment of this purpose, which seems to me of interest and importance, I shall indicate some of my own general conclusions.

The world in which we live is permeated with *structure*, of which we have not yet begun to realize and perhaps never can realize more than an infinitesimal part. A glance at the external world and also at the world within suffices to convince me of this fact. It is even possible that the structure outside and inside are intimately related—at least, it is only by means of our mental processes that we succeed in controlling the external world.

It is very natural, then, to examine the nature of the structure of thought. Here, as has been said above, the central fact is that there is structure only in so far as it is logical or syllogistic structure. In fact, in the gathering of experience we learn that A implies B: the child who comes too near to

the fire is burned; and therefore he remembers that this imprudent A implies this painful B. As his experience grows the array of similar implications extends, and at a certain moment he finds, further, that B implies C. By a basic law of economy of mental effort, he eliminates B, and realizes that A implies C.

From this point of view any train of thought may be regarded as syllogistic, even if not rigorously so. The main difference between thought in the animal and in man would seem to be that among the animals the only symbols which can be used are those afforded accidentally by external stimuli, whereas man supplies his own symbols at will. Through this symbolizing power man has been led to various syllogistic chains of fundamental importance for the comprehension of what goes on about him. It is the mathematician who has discovered, analyzed, classified the corresponding abstractions for their own sake.

Thus, where the ancient mind was confronted with a world of concrete happenings and things, the modern mind is faced by their manifold abstract representatives to such an extent that the happenings and things themselves begin almost to seem of minor importance. Perhaps, then, the principal philosophical difficulty of our modern world is that we find ourselves adrift in a cold, buffeting sea of impersonal abstractions.

Now when we survey the varied fields of scientific knowledge we are led almost inevitably to divide knowledge into five categories or 'levels,' characterized respectively as mathematical, physical, biological, psychological, and social.[1] Here it is not the number of divisions which is to be regarded as especially significant, for there are intermediate domains. The important general truths involved are the following: (1) Each level is a natural one in the sense that it possesses its own especial fundamental intuitive language which is largely

[1] For the points of view here expressed see the concluding chapter of my book, *The Origin, Nature and Influence of Relativity*, New York, 1925, as well as an article in the *Century Magazine* for 1929. The classification of the levels given below and the principles I-V are quoted directly from my book.

if not completely independent of that used in the other levels. (2) Every specific fact may be analyzed from any one of these levels taken as fundamental. For example, a child tosses a ball to another. The mathematician thinks of a sphere in space and time; the physicist, of a material body moving under the action of certain forces; the biologist perceives a biological significance in the act of play; the psychologist is interested only in the psychic accompaniment of the act; and the sociologist sees an instance of an important kind of social interaction. (3) According as we take one or the other of these levels as the most fundamental or 'real,' we are led to a corresponding systematic philosophic point of view.

These levels, together with the corresponding systems of philosophy and fundamental terms, may be catalogued as follows:

Mathematical, Absolute Realism:
Class, Relation, Inference, Abstraction.
Physical, Materialism:
Space-Time, Matter, Electricity, Uniformity.
Biological, Detailed Naturalism:
Organism, Stimulus, Function, Evolution.
Psychological, Positivism:
Sensation, Memory, Will, Idea.
Social, Ethical Idealism:
Personality, Freedom, Value, Ideal.

It may also be remarked that these levels form a kind of hierarchy in which the earlier levels are objective in the sense that they involve no explicit reference to personality, while the later levels are subjective, since they involve necessary reference to personality. The whole range involved may be termed the 'nature-mind spectrum of knowledge.'

It seems to be probable that those who take a particular one of these levels as the most real are merely those who insist on starting in their thought from this particular level; for instance, I, as a mathematician, would naturally consider physical, biological, psychological, and social knowledge in so far as it is embodied in abstract form. If this is indeed

the case, the only rational point of view is to regard all of these levels as having co-ordinate reality.

The acceptance of this conclusion is of fundamental philosophic importance; in particular we are led by it not to be overwhelmed by the merely physical aspect of the vast universe around us, and yet we are willing to grant that the physical world is so real that no set of mere abstractions can take complete account of it.

Now if the general diagnosis of our present philosophic difficulty made above is correct—namely, that we are confused by a large array of unco-ordinated scientific theories—it is especially desirable that we understand their nature and function in the domain of knowledge. With this in mind let us proceed to observe certain general facts.

I. Abstractions originate in the domain of the intuitively perceived.

This reminds us that abstractions are natural and inevitable in their beginnings, however elaborate their final form may be. Language itself is a vast loose abstract structure, which develops along with thought. Consequently the earliest and least sophisticated notions of the human mind mark the beginnings of genuine permanent abstract structures, however incomplete and erroneous they may seem to be later on. In any case, such notions may be regarded as important pragmatic attempts to ascertain the inner nature of the world by means of certain hypotheses which are more or less true. This leads us at once to the second general principle.

II. Every abstraction is to be applied in its appropriate domain of validity.

It has been the hope of many to find some final dogma. This tendency has been exemplified, for instance, by those who 'believed' in geometrical space in the sense of Euclid. But such persons forgot that the very process of measurement is so inaccurate that the geometric laws of Euclid can never be given a precise physical meaning; they also forgot that it was very unlikely from a philosophic point of view that

certain geometric aspects of the physical universe were absolutely independent of all other aspects. Today we prefer to grant an independent reality to space-time rather than to space or time. But we hesitate to regard our new point of view as an ultimate one.

Thus, more than ever before, we are inclined to look upon all abstractions as provisional and partial—as more or less extensive nets for holding a certain aspect of the truth. The same thought can be expressed in the form that all abstractions represent only a part the truth, with limited sharpness of focus.

Accordingly all questions concerned with the possibility of unlimited application of an abstraction should be abandoned as meaningless. For instance, is the world deterministic or not? Obviously one indeterministic happening in every æon of time is all that is required to make it indeterministic; furthermore, any series of happenings can be rationalized into deterministic form. Hence our query seems to be meaningless.

III. As more complete abstractions are made, they may be expected to include their predecessors.

In fact, since a more complete abstraction explains a certain group of facts and other new ones besides, it must be possible to show why the earlier theory is true to the extent observed. From this point of view any successful abstraction represents a definite step in advance.

IV. The undefined elements, relations, and postulates of a particular abstraction are to a large extent arbitrary.

An abstraction is merely a means of traversing systematically a certain structure of thought. Theoretically we can start where we will, although our actual choice of a starting-point may be governed by considerations of convenience; thus, in geometry we may begin with points, or with lines, or with convex regions as the undefined elements. No one abstract basis can be regarded as more fundamental than another, although it may be more convenient.

V. The usefulness of an abstraction is relative to its inherent simplicity of structure and its agreement with the facts.

Just because our minds are limited it is fundamentally necessary for us to employ the simplest abstractions which suffice to co-ordinate the facts before us.

This conclusion does not mean that a simple abstraction without present application is to be regarded as without value. All abstractions are significant if they possess beauty; and the experience of the race shows that such abstractions are almost certain sooner or later to prove useful.

With these general reflections concerning the field of knowledge, and more especially its abstract side, let us turn to the affirmations toward which they seem to point, particularly at what we have termed the 'social level.'

In accordance with the first of the five general principles, we are bound to give fundamental weight to all genuine intuitions, no matter on what level they appear. They form the basic material from which we take our abstract start, whether the level be mathematical, physical, biological, psychological, or social. In particular, ethical and religious intuitions are the fundamental material from which we start at the social level. These cannot be thrown aside, whether we will or no; and if we are wise we will give them the consideration which they call for.

The second principle leads us away from all dogma, except as a means of enabling us to grasp a certain partial aspect of the truth. Here by truth is not meant the narrow, literal truth, but rather pragmatic truth. For example, the Christian religion has contained forms of dogmatic belief which in their literal interpretation are now generally held not to be true. But in its basic affirmation of the deep unity of all personality and the transcendent power of love and good-will it has emphasized a truth of the first order of importance. Thus the pragmatic truth of Christianity (and of other religions) has been revealed by a positive, beneficial effect upon

personality. The forms by which this truth may be communicated function as devices which *work*, although no doubt it is often for a reason quite different from that which we think. In fact, it is often the case that our vocabulary of expression is so limited that we can only begin to grasp the essential truth in a realistic manner by means of forms which are incomplete and inaccurate. When we are thus forced to employ the imperfect means at our disposal, we should not hesitate in doing so. At the same time we ought not to cease our strivings towards a better understanding, since, according to the third principle, we can legitimately hope to succeed in our efforts.

The fourth principle teaches tolerance towards all forms of belief, since abstractions with different undefined elements and relations are often substantially equivalent. In general two theories are to be regarded as essentially equivalent when they lead to the same pragmatic conclusions.

Finally, in accordance with the last principle, we are led to estimate a social or religious code as a help towards a distant goal rather than as a final formulation, and as valid in an important sense only when it contains much of the truth in relatively simple form.

If the above general division of the field of knowledge is correct, religious truth falls at the social level. Thus God may be defined as the totality of personality, or rather as its highest form, which transcends our understanding. Since all personality must be definitely embodied and developing, if it is to be personality at all, God must possess a Personality as definite, for instance, as the particular physical universe around us. Moreover, since the totality of personality is unitary, all of its parts are definite and eternal, being constituents of a developing whole. Thus it is impossible, for me at least, not to conceive of life as ultimately triumphant over death.

Moreover, I am encouraged in this belief because I know how inconceivable is the range of abstract possibilities which may turn out to be actual. As Hilbert has recently declared: "We ought to know, we shall know." In other words, no logically conceivable task is beyond the ultimate power of

the human mind. I shall mention one possibility in order to illustrate my idea. Why may it not happen that a way will be found at last by which to *unite the past with the present*, so that personality can develop along the whole line of time? This would necessitate a new kind of time, related to ordinary real time much as the 'imaginary numbers' so fundamental for the mathematician are related to ordinary real numbers.

Thus my own tendency is toward a social and spiritual point of view which contains a considerable amount of faith, but no specific dogma. This faith appears to me to be justified in the same way as my faith at the other levels, in particular, at the mathematical level, and to be an equally inevitable result of my individual experience.

Perhaps, then, the primary service of modern mathematics is that it alone enables us to understand the vast abstract permanences which underlie the flux of things, without requiring us to regard its self-consistent abstractions as more than specific, limited instruments of thought.

RECENT DEVELOPMENTS IN LOGIC

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THE traditional manner of considering rationality envisaged it as a system of conceptual entities, of unchanging essences and laws, in an order established *ab æterno*. Rationality thus considered could not be reconciled with the creative activity of the spirit, and conflicted with the reality of history, which implies the possibility of the generation of new orders of existence. Hence abstract rationalism has always declared life in time to be an illusory appearance, and has sought in vain to resolve the antinomy of freedom and predestination. This mistaken manner of considering rationality was shared by the old empiricism, which was no less abstract than the rationalism it combatted, and which in its turn hypostasized an immutable order of laws in eternal nature, communicated to our consciousness through external impressions.

The first attempt to break through the iron circle of predetermined rationality is to be found in Kant, who considers the forms of intuition and the categories as modes of the activity of the mind. But at bottom he does not succeed in freeing himself from pre-formist prejudice; for him the *a priori* of sense and intellect still presents itself as a stereotyped form, which the mind discovers in itself by regressive analysis, but which it does not itself produce. We cannot help thinking in the eternal forms that Kant thought he could establish in his table of categories.

Hegel in his dialectic assumed the task of moulding rationality to the movement of history. Yet even he did not really succeed in introducing dynamism into rationality.

since the concepts of his logic, though set one after the other and linked by an intrinsic necessity causing us to pass perpetually from one to the other, are still the old abstractions of hypostasized intellectualism, enclosed in a circle in which our thought must go round and round for ever. Now this continuous circular motion is a simulation of process, but no real and historical development. Where the stages of thought are predetermined, there is no true process. There is no freedom where the mind is constrained by necessity to traverse always the same concepts, the same determinations of reality, unchanging and unchangeable.

The traditional manner of considering rationality, as a system of closed concepts and relations, failed to satisfy our indestructible need to attribute a meaning for our life as it evolves in time.

If the whole of reality is already complete and perfect in an eternal order, there remains nothing more to do in the world. All the strivings of our busy wills must be in vain. Hence a profound discord between logic and life. But as we shall see, this discord, that became acute towards the end of the last century, has been gradually attenuated by the new developments of contemporary logic; it is possible to envisage rationality in a truly dynamic manner, so as to make it correspond to the most concrete exigencies of life and history.

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Hegelian dialectic answered a real need: to provide us with the concrete universal. The old logic attained to unity by obliterating differences. Rising step by step to concepts of ever wider generality till it reached the idea of simple Being, it progressively diminished their content till this was wholly eliminated. Thus all the wealth of concrete determinations was lost, and unity, thus attained, unified nothing, for it fell outside multiplicity, which it did not synthesise, but on the contrary excluded. The concrete universal, on the other hand, which Hegelian dialectic seeks to

construct in its process, is a synthesis in which all the determinations of reality are preserved—the living organism of thought. The old logic, from considering the concept in its identity and immutability as something real, was led to exclude change. It was Hegel's merit to have discovered that every contradiction is relative to a certain unilateral outlook on reality, and that if we raise ourselves to a higher and more comprehensive standpoint our thought can embrace and reconcile in a wider outlook two fragmentary views that seemed to exclude each other if considered from two unilateral viewpoints.

It is evident that the Hegelian dialectic works outside time in a closed cycle, turning and returning eternally upon itself. In fact, it contains no true process, for the whole system of categories is given from the beginning. And it is not comprehensible how Absolute Thought, that in itself contains the full concreteness of all determinations, should have to return and retraverse the unilateral and abstract concepts. In conclusion, in the Mind of God, in the Absolute, there is no sense in speaking of a dialectical process. Such a process has meaning only from the viewpoint of the finite mind, which does not comprehend in itself the whole fulness of reality, and is therefore constrained to unilateral and abstract views.

This manner of envisaging dialectic, that is, as the successive approximation of human thought to the system of the Absolute, overcoming the abstractions and contradictions of our intellect step by step, was maintained by the Italian philosopher Vincenzo Gioberti towards the middle of the nineteenth century.[1] And the British neo-Hegelians, especially Bradley and M'Taggart, towards the end of the nineteenth century, conceived of dialectic in the same manner. This perfectly coherent system is the criterion of truth, immanent in the human consciousness, which, being bounded and fragmentary, lays hold of certain groups of relations detached from others, and only under certain one-sided aspects. Our consciousness never, therefore, gives us full

[1] In the last phase of his thought, when he drew near to Hegel.

reality, and is constrained to reconstruct by means of abstract concepts the synthetic unity that for ever eludes it. Judgment, says Bradley, is always inadequate; by judgment we qualify what is given us in experience, a certain subject, a certain *that*, by a predicate, a *what*. But like all other relations, this gives rise to contradictions. Qualities cannot exist save in so far as they are distinct, that is, they imply at least the relation of diversity. But relation in its turn has no sense save in as much as it holds between certain terms, of which it therefore presupposes the existence. Moreover, if the relation is thought of as something distinct from the terms, there arises the problem of understanding its reference to these terms. This involves the understanding of an infinite series of relations and the series will never be closed, for our finite thought can never embrace the totality of relations. Science, which seeks to understand reality by relations of space, time, cause, substance, etc., goes round and round, therefore, in a world of contradictory appearances.

While Hegel accepted the categories and concepts of the science of his time without demur, and, while proclaiming them abstract, transported them into the eternal cycle of his dialectic as moments through which thought must always pass, the new British Idealists, while taking their stand in opposition to empiricism and evolutionism, recognise the relative character of scientific concepts. They are *working ideas*, according to Bradley, who in this agrees with his Pragmatist adversaries. But, though partial aspects, they do not fall wholly outside reality. The whole and completely harmonious system of the Absolute must comprehend them all, allotting them their rightful place, integrating and correcting their abstraction. Even an appearance *is*, and hence must somehow belong to reality. There is no error that does not contain a certain measure of truth. The appearance that, in order to be converted into an absolute, requires less *addition and rearrangement* possesses a greater measure of truth.

And here it is that the inadequacy of Bradley's logic reveals itself. Extremely brilliant and penetrating when employed in negative criticism, it is unable to give us any

positive criterion whatever of truth. How, indeed, can we measure the degrees of truth?

Once reality is postulated as an already given whole in a total and eternal synthesis, British neo-Hegelianism is unable to assign meaning to our life in time, to the world of our human experience as it evolves in history. One fails to understand why what is already made should need to remake itself. Thus dialectic ends by owning its own inadequacy and by appealing to the irrational. This is plain in that immediate intuition of which Bradley speaks, and in the mystical love that is the final recourse of M'Taggart.

For M'Taggart, indeed, dialectic has only a purely subjective value. It is not for him as for Hegel the very process of Absolute Reality, but only the mode in which the finite consciousness attains thereto, by progressively freeing itself from error.

One might ask M'Taggart what remains for us to do, and what gives rise to time, to which we cannot help assigning a certain form of existence. If it is outside the Absolute, how can one envisage its coexistence with the Absolute? To call it an illusion does not dispense the philosopher from the task of explaining this illusion. The deeply human problem of bestowing a meaning upon our life in time in M'Taggart's static conception remains unsolved. To solve it we should have to bring the Absolute forth from its immobility, to give it the motion and warmth of life by recognition of the reality of change. And such has been the endeavour of Bosanquet and Royce.

For Bosanquet dialectic is not purely subjective and illusory, but reproduces the inward dynamism of reality. It is not the simple contradiction between abstract concepts, but the concrete opposition between the various parts of the world of our living experience. Bosanquet, while reducing everything to thought, uses this word to signify the whole of our spiritual life enlightened by the light of consciousness, thus including feeling and will.

The very fulness of dynamic life, which includes in itself all the contrasts of the world, all the infinity of time over-

come in its eternal present, is to be found in the Divine Consciousness as conceived by Royce. It is the eternal significance of all our ideas; that is to say, it is the ultimate end they seek to realise, since our every thought is at the same time an act of will. In it alone is there an end of all ambiguity and of that indetermination that is present in all knowledge, in all human judgments. But it contains also imperfect truths, partial satisfactions, errors, as unilateral views in the total vision of the Absolute, in which they find their complement and correction. It would seem that thus Royce preserves the life of time, transferring it with all its joys and sorrows, with all its falls and all its victories, into the very life of God. But in reality, if everything is already done, the prospect of the future is only a fallacious semblance, due to our own fragmentary outlook. We delude ourselves that there remains still something to do, when all is already done. It avails nothing to appeal to the new mathematical theories of Dedekind and Cantor, for the infinite, if it is truly infinite, must be thought of as inexhaustible. Instead, if all the terms of the series of time are considered as already given, if their synthesis is put forward as completed, it is already exhausted. History, which we believe we can still construct, is already constructed down to the smallest detail.

For the historical process to be truly real, the spirit must have the possibility before it of ever fresh creations. Every fixed limit confining its activities must be removed. To this task Italian neo-Hegelianism set itself. According to Gentile, Hegel's mistake lies in having placed the Idea and its dialectical development in itself and in nature before placing it in consciousness, forgetting the Kantian discovery of the categories as an activity of thought and the necessary presupposition to any concept. Dialectic must not be applied to objects thought, which in themselves are abstractions, and for which the old logic of identity holds good, but to the very activity of thinking which in every one of its moments is full concreteness. Beyond or before this concrete act nothing exists. The study of objects must be left to science;

philosophy is reflection on the concrete activity of thought and cannot avail itself of the method of abstract logic, since the spirit is not something that can be contemplated as a fixed object with immutable properties. One cannot say its activity *is*, but that it *becomes*. Its reality lies in its eternal self-making. Thus it cannot be understood otherwise than dialectically, for its life realises itself precisely in the continuous transition from being to not-being, in which it renews itself in a process of inexhaustible creation that is at once its own history and the history of the world. But this concrete logic cannot realise itself save in as much as thought, in its necessity of self-objectivation passes eternally through the old logic of identity, which is always being reborn always to be overcome. To reflect on itself, the spirit must issue forth from its immediacy and objectivate itself; but in this objectivation it seizes only the past moment, that which no longer is. It apprehends itself as nature, not as spiritual activity. The life of thought, in its concrete actuality, is to be found in this eternal transition from subjective immediacy of feeling, which in art gives its own colour to everything, to the objective moment, which is religion, in which the subject denies itself in order to oppose to itself an infinite object. Thus Gentile, returning to Fichte, concentrates dialectic in the act of self-consciousness, in that which for Hegel was only the final triad of the process. And in these three moments Gentile vainly endeavours to confine all the functions of the spirit. Thus the negative moment, the anti-thesis, the not-being, gathers into its indetermination our past, all other empirical individuals, nature, law, God, error, evil; and when the philosopher says that these are born from the abstract objectivation of thought, he does not give any reason for their diversity. Nor does it avail to say that no two moments are identical, and that therefore the thinking activity in its self-objectivation engenders infinite distinctions, for in that way all distinctions would be set on the same level. God, for instance, would be distinguished from a human individual as one empirical person from another, and one fails to understand

why God should be worshipped and not this or that person. Moreover, only by an artificial and arbitrary definition of art and religion, making them present themselves as opposites, is the dialectical passage from one to the other rendered possible.

A greater respect for concrete distinctions is to be found in Croce's *Philosophy of the Spirit*,[1] in which attempts a more radical reform of the Hegelian dialectic. In accordance with reason he abandons the attempt to create artificial oppositions where they do not exist. Oppositions, according to Croce, exist only in the ambit of each function. Thus in art we find the antithesis of beautiful and ugly. For these contraries the dialectical principle holds good that reality lies in the synthesis of the two, that is, the positive is realised not by the exclusion of the negative, but by including it in its higher concreteness. But in the relation between the various forms of the activity of the spirit there is distinction, not opposition. Art, for example, as intuition of the moment of individual life, is the first grade of knowledge, from which the spirit rises to the higher grade of philosophy, the thought of the universal in its concreteness, in which intuitions are not eliminated but comprehended. The first grade exists as a moment distinct, not separate, from the second, which instead implies the first, for there is no thought without intuition. In the same way the moral will, which is the higher grade of the practical activity, implies the lower, that of utilitarian value, for it is not possible to will universal good without at the same time willing a particular good. But the economic will, which aims at the useful, subsists as a distinct and independent grade from the moral will. And a relation of distinction must be posited also between the theoretical and practical activities, for action presupposes thought, but thought can subsist as a distinct moment of the life of the spirit. This ideal succession of moments (not to be confused with a real and historical succession), is what Croce calls the dialectic of distincts. These have concrete subsistence in

[1] Needless to say, here as elsewhere, I am following a logical and not a chronological order.

consciousness, for they can be distinguished in the unity of the spirit, which comprehends them all in its every throb of life. The opposites, on the other hand, are abstractions that have no reality distinguishable of one from the other.

There is no *a priori* justification for the ideal order of moments, and less still for the eternal circle conducting the spirit eternally from one to the other. As a matter of fact these determinations of spiritual functions are not dialectically constructed, but drawn from experience. The schema of distinction, like that of opposition, does nothing but distort them, defining them *a priori*, in such a way as to enable them to be ranged in that given cycle of categories. And the speculative method, without rule or check, making of sole subjective thought a norm unto itself, can construct its table of spiritual categories at will. And this varies according to the philosopher. Thus theory and practice are identical for Gentile, while they are diverse for Croce.

It is now time to shatter these last constructions in which rationalism, convinced of its impotency dialectically to construct the categories of the natural world, would seek to confine the forms of the spirit. There is no circle in which our conscious life is condemned to go round and round forever. The claim to characterise these forms of all eternity is illegitimate. Thus the categories of the world of nature, like those of conscious life, are not fixed patterns or rhythms through which experience must pass eternally, but variable constructions in which empirical activities, while losing nothing of their concreteness, find co-ordination through the integration and enrichment of their life. Mutable forms, in their concrete historical development, in which they assume individual aspects that are always unpredictable, they perennially shatter the old equilibriums and give rise to fresh syntheses, in which both they themselves and their dynamic relations are transfigured. Hence we set a false problem when we would settle once for all what is art and its relation to religion or to philosophy, or would determine infallibly the nature of Right in its relation to moral life. History knows nothing of fixed paths on which it must move

eternally in courses and recourses; it builds its own road, testing and retesting, in order to compose its living energies in ever higher forms.

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To a superficial gaze Pragmatism and Intuitionism are the antithesis of neo-Hegelianism, and the philosophers of the two hostile tendencies have waged long warfare. But, at bottom, there is a common aspiration: that of equating logic to life, of rendering it concrete, thus overcoming the old abstract rationalism. This tendency is the hall-mark of the nineteenth century, which was historicist and evolutionist, in contrast to the eighteenth, with its idols of a motionless Nature and a motionless Reason. The theory of evolution, in fact, gave birth to Critical Empiricism, which brings logic back within the development of life, considering it as an organ of biological adaptation. The myth of the immutability of logical forms has been overthrown, together with that of the immutability of organic species. Not only that, but while the transformation of living species remains an unverifiable hypothesis, the evolution of mathematical and physical concepts, of the principles and categories with which scientific theories are built up, is an undeniable fact to be observed in the second half of the nineteenth century. The construction of non-Euclidean geometries, the crisis of mechanism resulting from the discovery of the second principle of thermo-dynamics, the rise of the science of energetics, the new studies on the transformation of chemical elements, all lead scientists to put away their traditional prejudice in favour of a single type of theory, an immutable logical structure, through which the complex of phenomena must necessarily pass in order to be known. Innumerable theories, starting from different primary concepts and different primary relations, are equally possible. And among them there may be free choice, so long as their consequences are borne out by the facts. The old categories of cause, substance, action, no longer appear as indispensable logical forms if phenomena are to be intelligible. In fact,

following the lines traced by Rankine and Mach, there is a readiness to replace them by the concept of a mathematical function between certain variable magnitudes.

A profound revolution in method has thus taken place, seeming at first a discrediting of science, a crisis of human reason, and liable to encourage mystical castles in the air and emotional vapours. But what has really happened is that it is the old, dead Goddess of Reason of the eighteenth century who has tumbled from her altar, to make room for a living Reason which does not mirror immutable reality from without, but places itself in the very heart of reality, and actively contributes to its development.

As when we were dealing with neo-Hegelianism, in treating of Critical Empiricism, Pragmatism and Intuitionism, we shall avoid the barren standpoint of negative criticism, preferring to emphasise their positive contribution to this idea of a new logic moulded to the movement of life. When Avenarius and Mach tell us that concepts are organs for a better adaptation of the organism to the world of its experience, and that their purpose is to master it in the simplest and most economical manner, the concept does not lose but gains in value.

Assuredly Critical Empiricism has its defective side. As when it claims to explain the tendency to unity by the need for mental economy, taking into consideration only the simplicity of the *schema,* which is the sign for the concept, and leaving out of account the highly complicated dynamism of mental operations in which its true reality lies, a complexity that increases more and more with the ascent to more general concepts.

The Pragmatism of James, Schiller and Dewey undoubtedly reaches a higher level than Critical Empiricism, in as much as it rejects the atomic resolution of the Ego into a mere aggregate of elements, and insists on the continuity of the stream of experience, in which data and relations can be isolated only by abstraction. The individual activity of the subject in the construction of things and concepts is vigorously asserted. Critical Empiricism continued to con-

sider the concept as a mechanical result, as the precipitate of a series of sensations, and, while assigning it an active function, reduced it to a complicated mechanism of reflex actions such as the word or definition of the concept might suggest. It reduced the mental act to a kind of representation of actual physical movement. In Critical Empiricism the materialist and determinist outlook on life and its adaptation had yet to be overcome. Pragmatism, on the other hand, attributes a real efficacy in world-construction to the human will. And here precisely lies its undeniable merit, as contrasted not only with the old rationalism, which conceived of reality and truth as something ready-made, independent of our working, but also with British neo-Hegelianism, which, as we have seen, posited over against human conscious and prior to it, an Eternal Consciousness in which the whole system of reality was contained and exhausted.

Having denied that a total and divine system, of which we can humanly form no idea, could serve as unit of measurement of degrees of truth, Pragmatism felt the need of a criterion that would be effectively applicable, and believed that such a criterion was provided by social utility, whether of concepts, principles, or logical structures. The *convenience, suitability*, of which James, Schiller and Dewey speak, does not mean the mere satisfaction of the individual, but also that which renders social agreement possible. And there are certain conventions, such as those of logical principles, which must be respected if men are to understand each other. But in this wider sense utility becomes a very vague expression and can be made to cover almost anything. And here precisely is the weak point of Pragmatism: its criterion of truth remains indefinite. We must explain what we mean by social utility. Is it maybe the greatest happiness of the greatest number of individuals? But by now, since John Stuart Mill, the qualitative distinction of forms of happiness and the need to place them in hierarchical order has become a commonplace. We must appeal to an end, to a higher norm of valuation. And if the useful is taken as that which corresponds to the ends of society, these ends still re-

main to be determined. What is the ideal towards which the life of experience, in which we all participate, is tending? Schiller speaks of a final harmonious perfection of activity. Dewey describes the evolving movement of experience as the rise of conflicts within it, leading to the relative distinction of data and ideas that serve to rearrange, reorganise and harmonise it. But it is just the meaning of the word *agreement*, of the word *harmony*, that the Pragmatists fail to explain. They over-emphasise the action of the subjective factor.

But if we turn aside from these paradoxical exaggerations, which are the ephemeral part to which, from controversial motives, in reaction to chill intellectualism, too much emphasis has been given, and if we consider more intrinsically the meaning of the formulas *convenience, utility, power of action and of foresight,* we see that at bottom they signify the concrete agreement of our human wills in a world of experience unified by our concepts so as to make it converge towards the realisation of our ends. Here, then, is the same aspiration towards the concrete universal that we emphasised in neo-Hegelianism. They place the criterion of truth not in that perfectly harmonious system, immanent in our spirit as an immutable model, but in the process of action by which it is realised, and which, by its success in the world of our experience, affords us proof of the ever vaster agreements we are gradually achieving by our logical constructions.

The same tendency to reabsorb logic into the movement of life is to be found in the Philosophy of Action and the Intuitionism of France. Assuredly, if scientific knowledge is made to consist in reduction to identity, it is easy to show with Boutroux, Milhaud and Meyerson that concrete reality, in the wealth of its changing aspects, falls outside our formulas. And it is this abstract mode of understanding the concept, as a rigid schema always identical to itself, that Bergson rightly judges to be incapable of giving us understanding of the process of continual renewal, of inexhaustible creation, that goes on in our living experience. But there is another manner in which the intelligence may be con-

sidered, and that is in the concrete spiritual process of its active production—not the ready-made concept, not the already petrified lava, but its incandescent flow before it cools and becomes stone.

Le Roy insists repeatedly on the fact that intuition is not opposed to intelligence, but reintegrates the intelligence in itself by seizing it in its living dynamism. It is reason, not immutable and enclosed in an eternal codex of laws, but evolving in an inexhaustible process and able to create new rules and new categories—reason, which operates, and which in action experiences its truth.

Intuition thus approaches Pragmatism. But Le Roy refuses to allow the intervention of any extraneous or alien motive, any consideration of convenience or of utility of a lower order, in the determination of truth. Fruitfulness must be homogeneous with the order of thought in which the theory evolves. The true idea is the idea that bears fruit, but in the domain of knowledge itself, not in that of industry or even of feeling or moral comfort. It is the idea conceived as a scheme, as a plan of battle, and which fulfils its promise, triumphing precisely in the action it suggested.

There still remains much that is indeterminate in this way of envisaging truth. Fruitfulness in the realm of knowing can only signify the capacity to make us discover other truths, and thus to enrich our knowledge. It presupposes that we have already determined the sense of just that word, truth. And since we must rule out other ends we must determine the end of cognition, since the idea cannot undertake to realise another plan diverse from its special cognitive function. But in what does this cognitive function consist? Here is the essential problem, and Le Roy leaves it unsolved. But he is to be noted for his brilliant endeavour to introduce reason into the very movement of life, directing intuitionism towards that concrete and dynamic rationalism to which, as we have seen, the development of contemporary logic tends.

The dialectic of the moral life, according to Blondel, should carry us instead beyond experience. The principle of contradiction does not lie in facts, which can neither pro-

duce nor suggest it. Opposites are such in virtue of their agreement or disagreement with the trend of our tendencies. The notion of the contradictory comes to us from the feeling of the irrevocability of what we have willed. The real and original meaning of the principle of contradiction is that of establishing that what might have been, and what in virtue of our action might have become part of what we are, is ruled out for ever, and yet does not cease to enable us to think distinctly what has been chosen and done, nourishing the effort of knowledge and execution, and giving moral determination to both the realised act and the agent. Whereas abstract negation destroys the concept denied so that no trace remains, the privation of anything leaves the scar of the act that retrenched it in the potentiality that could have realised it. Not only what we do but what we renounce contributes to our making. Repressed tendencies remain to point the meaning, to determine the cost, to nourish the life of the tendencies that triumph. Our option once made neither of two contraries survives alone; a new reality is created. A realised idea is no longer the same as it was before it was chosen from among others and opposed to others. The sum of human activity thus does not develop along the line marked by the simple, clear idea that, maybe, we think is our sole guide. The logic of life unfolds along the diagonal of the parallelogram of all concurrent and co-operative forces. In this logic truth is the agreement of thought and life with itself, not in the purely formal sense, but in the concrete signification of a complete equation of what we do, of our realised will, with what is implicit in our deeper will. And this deeper will does not realise itself all at once, but achieves itself little by little through the resistances offered by sensible nature, by the bodily organism, by human society, by the whole universe. Blondel's dialectic of action works itself out in showing how the deeper will realises itself through the co-operation of contrary forces, urged on from stage to stage by the discrepancy between what it has realised and the infinite Being it aspires to possess, till it reaches the final choice between the incomplete

satisfaction that is all that can be obtained in this wor possession of Absolute Reality, in which alone sh deeper will be satisfied and our being find full realisa vital option that expresses itself precisely in the prir contradiction: either to be, with God, or not to be, finite world.

Whatever the value of Blondel's Philosophy of bears vigorous witness to what we consider the fu motive of the development of contemporary log the demand for a concrete rationality that shall r to the movement of life.

The new theories of the deductive and inducti tend in the same direction, emphasising the crea of thought in all reasoning. The old school logi reasoning consisted in the subordination of one another and wider one, is now cast aside. The contained in the premises, but is something new structed. Mathematical reasoning, says Goblot, passage from the general to the particular, but th from one property to another and heterogeneous (from the equality of the sides of a triangle it deduc equality of the angles) or to a more general property from the theorem of the sum of the angles of a triangle we pass to that of the sum of the angles of a polygon). Poincaré believes he has discovered the foundation of generalisation in mathematics in recurrent reasoning, in which it is proved that if a theorem is valid for 1, for n-1, and for n, it is valid for all numbers—a reasoning that has as basis a synthetic *a priori* judgment. It is to Goblot's credit to have insisted on the constructive character of mathematical knowledge—a fact that already, at the beginning of the eighteenth century, the genius of Giambattista Vico had clearly intuited and expressed: GEOMETRICA DEMONSTRAMUS QUIA FACIMUS.

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The old geometry frequently appealed to intuition. Recent developments in mathematics tend, on the contrary, to give geometry the form of an abstract, logically rigorous

theory, in which all the concepts and all the propositions we employ are explicitly enunciated. Even the evolution of mechanics has induced scientists (such as Rankine, Mach, Ostwald, Duhem) to strip their theories of representative elements, and if other physicists like Faraday, Thomson, Lodge, Maxwell, Garbasso, have recourse to concrete mechanical models, they admit that these images may vary, and consider them equivalent if they represent the natural relations of phenomena equally well. Hence representative elements have come to appear, in their variability, as something accidental in respect of the constant relations symbolised by such models.

The result has been to reduce every physical or mathematical theory to an assembly of logical deductions drawn from a certain number of primary relations (postulates), which are asserted as subsisting between certain primary and indefinable concepts. The entities and the primary postulates may be chosen at will. Thus, instead of starting from the straight line and the plane in order then to define the sphere, Lobatschewsky in his non-Euclidean geometry defines the right angle and the plane by means of the sphere. The principles that serve as starting-points have not the character of self-evidence they possessed for the old rationalism.

There are, however, certain conditions which must be satisfied by the primary entities and primary propositions. Terms left undefined must be such that by their means every other term can be defined, and propositions left unproven such that from them all the other propositions may be obtained by the sole use of formal logic, without any appeal to intuition. Other necessary conditions are the independence and mutual compatibility of the primary propositions. It must not be possible to deduce one from the other, and they must not imply any contradiction.

Mathematics having thus assumed an abstract form through the elimination of any remnant of intuition, they have tended more and more to identify themselves with logic. Mathematical logic, or Logistic, has thus arisen, in which logical concepts and operations are symbolised by

signs analogous to those of algebra, particularly through the work of Boole, Schröder, Pasch, Peano, Whitehead and Russell. All these logicians are agreed on the value to be assigned to mathematical theories. These, according to Pieri, a disciple of Peano, are hypothetical deductive systems, that is, they always take the form: "if the hypotheses posited at the beginning are true, these consequences necessarily follow."

One of the basic conceptions that the new realism has taken from mathematical logic, and which forms, one might say, their main decisive weapon against the idealism of Bradley and Royce, is the doctrine of the exteriority of relations.

Meinong, too, as against the intemperance of Psychologism and Critical Empiricism, has maintained the legitimacy of a *Theory of Objects*, that is, of a theory of rational essences, independently of any consideration of existence, and he has gone still further than Russell, for he admits even impossible objects, beyond the compass of our thought, such as the round square!

The self-subsistence of the immutable essences even before they are discovered by consciousness is a dogmatic assertion made by the new Realism, and one which, while it can in no wise be proved, gives rise to insuperable difficulties. How can it ever be possible to explain the varied grouping of these entities and these relations in such a way as to engender the phenomena of our human experience? According to the New Realists there is an entity *red*, an entity *round*, an entity *consciousness*. But how is the fact objectively produced that at a certain moment I think of a red ball? It will be answered that the three entities come into relation. But this relation in its turn subsisted immutably from all eternity. How will it ever be possible objectively to determine the fact that this relation subsists in this moment between these three entities and not between an infinite number of others?

The hypothesis of the self-subsistence of the universals does not help us at all. So long as they remain in isolated

self-subsistence they mean nothing to us; their function begins when they enter the world of our conscious experience. That the principle of causality, for instance, should be an eternal essence does not concern us at all. What we want to know is whether it is universally valid for our experience. You tell me that the principle of causality can enter into relation with other elements of our world. But who assures us that it will do so, who guarantees that it will always hold good in our world? In final analysis, if we remain in the pure domain of the essences, we have before us infinite possibilities that may combine into infinite systems. Which of these theories may be true for our world only experiment can decide. Russell agrees in this, and he, too, recognises, therefore, that some of the categories now used in scientific systems may be cast aside if others will serve the purpose better. But then what is the good of supposing them eternal in their essences? And who authorises Russell to project the logical constants that are the result of his personal analysis into the heaven of eternity? Other mathematical logicians consider other concepts and other elementary relations as the primitive ones. The analysis of the world of our experience may be made in an infinity of ways from an infinity of viewpoints. How can you claim to fix the results of analysis once and for all? Russell reduces philosophy to a repertory of abstract possibilities, and believes that thus he is widening the horizons of thought beyond what is actually experienced. But he supposes these abstract possibilities as already given from all eternity. And we hold that the true infinity, which does not limit thought, is one which, far from being exhaustible in a repertory of eternal essences, allows the human spirit the power to create new ideal orders, new categories unregistered in any inventory.

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We have seen how the recent developments of logical theories converge towards an idea of rationality corresponding dynamically to the life of history. But we noted at the

same time a lack of any precise determination of that concept of concrete truth, and above all the lack of a criterion that would enable us to measure its degrees and liberate us from arbitrary dialectical constructions, subjective satisfactions of sentiment, or dogmatic acts of faith. This criterion, to my mind, should lie in experiment, which, at bottom, we all accept in the domain of science, and which should also enable us to find a common ground of agreement in that which concerns philosophic truth.

The traditional theory that makes truth consist in a correspondence of human thought with things in themselves, and for which our ideas are simply reproductions of objects or objective essences, cannot be reconciled with the method of experiment. For an experiment is an action modifying reality more or less profoundly, whereas, according to the old criterion, we should mirror reality without contributing anything of our own. Thus experiment, as regards both its starting-point and its goal, is an active modification of reality. It does not reproduce an order of things and facts as existing in themselves, as naïve realism depicts them to the imagination of the vulgar, but produces always something new. Let us take one of the simplest experiments, that of the motion of the pendulum. The physicist takes a very fine thread, of which the weight is negligible as compared with that of the little ball attached to it, and causes it to oscillate in a vacuum so as to eliminate, as far as possible, the effects of friction. In other terms, he arranges the conditions of the phenomenon, combining them in a suitable manner so as to make them approach a certain ideal type. And not only does he intervene thus actively with his thought at the start, constructing a situation, which without his action would not have existed, but he intervenes also at the end, elaborating the result of his experiment. He does not limit himself to noting down the bare data of his various observations, but he adds them up and subjects them to calculations in order to obtain the most probable averages of the different numerical values obtained by his measurements. He generalises them and brings them to the ideal synthetic perfection of the

law of isochronism, to which experience may approximate, but which it never attains in any precise manner. All the principles of physics, all its laws, are ideal constructions of this nature. They are typical models, which do not merely sum up the facts experienced, as naïve empiricism might suppose, but which are actively produced by our thought; our thought pursues on its own account and brings to an ideal limit of perfection the process which actual experiment can only approximately fulfil.

We have chosen one of the simplest facts that comes closest to sense data in order to show that even here thought is operative, but it would have been far easier for us to emphasise the action of the physicist in more complex experiments, when, as with the phenomena of electricity, the bare data have no direct reference in themselves to that hypothetical energy. It is the scientist's mind that, by interpreting them, sees magnetic fields, positive or negative poles, transmissions of currents, discharges of electrons, where the senses present us only with wires and pieces of metal, glass tubes, sparks, movements of pointers, registering apparatus, and so forth. We may therefore legitimately conclude that experiment is not the passive mirror of a supposed nature, as realism would have it, beyond the action of our thought, but is an active transformation of reality, generating new situations, new concrete forms of existence, new orders of facts. Science does not confine itself to reflecting on something presented to it from without, but it produces new bodies and phenomena, and realises modes of action that would not exist in nature without its work.

In what does experimental verification consist? The physicist formulates an hypothesis and, taking it for guide, acts in the world of his experience. If he achieves the end proposed he asserts that the hypothesis is true. Otherwise he says it was false and modifies it. In the first place, if we consider carefully, an agreement has been attained between the actions of the physicist and the other innumerable activities of the world of his experience operating in that particular situation. That is, the physicist's actions and the other activi-

ties have agreed, have worked in co-ordination, so as to obtain the result.

The agreement of which we speak is not a resemblance, still less an identity of the acting forces. Each of these may have a widely different character from the others. It is enough that they should converge to the same end. It is a harmony of the kind that is realised in living organisms, where heterogeneous processes work in co-ordination so that the conservation of a given individual results. Concrete unity, therefore, not abstract identity: that is what the physicist produces, setting his theory to work in an experiment that confirms it. The varied action of the highly complicated apparatus in his laboratory, and through which the energies of the universe operate, and the activity of the human organism, in which thought manifests itself with its ideal conceptions, agree and work in co-ordination for the achievement of one and the same end, without loss of characteristic physiognomy to either. In scientific truth, this understood, intuition is not obliterated but enriched and potentialised. And, at the same time as intuition is enriched, the reality of experience attains an ever increasing harmony. The experimental action of scientific concepts renders reality more coherent; it composes forces in more regular rhythms, it installs an ever vaster and more perfect order. There is no work of man, there is no machine, in which this transformation is not apparent. The electrical waves, for instance, engendered and received by human apparatus are produced with a greater regularity than that of those existing in a state of nature. And different energies, independent one of the other before our action, come to be combined in the physicist's instruments, so that he makes them co-operate in the attainment of the same end.

Science, in short, is engaged in rationalising nature more and more. This must not be taken as if forces had been hitherto incoherent, but in the sense that there is process from a lower to an ever higher harmony. The physicist always starts from a situation that has a certain degree of coherence, but the new experiment aims at realising a more

complete agreement between the forces involved, and at extending it to others that had not previously been co-ordinated with these. We can speak of disorder in only a relative sense, that is, always in comparison with a higher harmony.

When concrete rationality, that is to say, the *progressive co-ordination of the activities of the world of our human experience to converge towards the same end,* is thus understood, it is clear that there can be infinite degrees of rationality, of truth, of reality, in accordance with the greater or lesser vastness of the field of actions that reach agreement in a determined theory. Higher truth is characterised by a more comprehensive synthesis, and is that point of view that succeeds in embracing the partial truths of lower viewpoints, and of including in itself a greater wealth of intuitions. In respect of this higher form of rationality lower orders may be called relatively irrational, but one can never speak of the irrational in an absolute sense. However far back we may go we shall never reach an experience that does not comprise already some form of unity or rationality. There is no intuitive life in which thought in a more or less embryonic stage is not immanent. Thought, like the life of experience, is not something derived. If we try to explain its genesis we presuppose it by the use of certain categories. The distinction between what is given and what is thought can only be relative. Every scientific experiment, every philosophic reflection, every activity of thought, starts from a certain initial situation which, in respect of that thought, of that reflection, however lofty, constitutes the *relative datum.* But this datum already contains the work of previous reflection or construction. The fact from which the scientist starts in each new research is a certain situation of the world of experience, which has been already interpreted in terms of the logical, mathematical and physical theories of that historic moment and of the philosophic conception implicit in these. He does not start from the particular in order to rise to the universal law, as naïve empiricism imagines, but from a given situation that is at once particular and universal. The problem of what was claimed to be the transition from the particular to

the universal is badly set, and is therefore insoluble in the old terms. Induction is instead the transition from a certain logical order of experience to another richer and more harmonious.

It is as organs for realising this ever vaster and richer harmony of the universe that the logical principles must be understood. They do not serve to assure an abstract identity, but they are rules for the co-ordination of our thoughts and intuitive activities in their convergence to a common end. Those ideas are practically equal for us that allow us to achieve this concrete agreement in our actions. The only possible verification of the relative identity of our concepts lies in experiment. We say that we have the same concept when in speaking or otherwise making use of it we succeed in reaching an understanding with other men or with ourselves. This does not exclude the concrete variety of thoughts, nor does it exclude change. It merely assigns certain limits within which these variations must take place so as to enable the concrete agreement of our human activities and of all the activities of the world to be realised. The concept is not a simple essence that can be immediately intuited, either within our consciousness or beyond it; it is a constructive process, a complicated dynamism of relations, a more or less complex series of mental operations, which the word or sign serves to symbolise. The definition of the concept determines the rules of this construction, the operations that must be carried out, the limits within which the activity of our thought must take place. But within these limits the process may assume an innumerable variety of forms both in ourselves and in other individuals, provided that a concrete harmony of actions is obtained.

This agreement is the aim of all logical structures and all mental categories, which are active constructions of our thought, and through which an ever vaster and richer co-ordination is realised between our activities and all the forces of the world. And thus the world, together with ourselves, is raised to a higher grade of concrete rationality. Like scientific theories, our philosophic syntheses must likewise be

put to the test. For metaphysical ideas, too, are energies operating through our minds in the concrete reality of experience, and in respect of them, as in respect of scientific concepts, we may ask ourselves if the actions they suggest or the modes in which, in their ensemble, they modify the forms of our activity, realise a higher harmony of the forces working in the world.

Every philosophic conception is an endeavour to compose the activities of the universe in a richer harmony, to establish an ever fuller rationality. There is no absolute rational order that our consciousness is compelled merely to mirror; instead, there is the realisation of ever more complete orders, with the vigorous collaboration of human thought. Philosophy is not Minerva's owl, which, as Hegel said, begins its flight only in the dusk. It does not reflect merely a development of logical categories already determined in the necessity of their process, but it also creates fresh categories. It constructs a higher grade of rationality which previously did not exist. It concentrates, in the experiment of its supreme synthesis, all the forces working in history, to make of them a single renovating energy. It is not a sunset in which the spirit recollects itself to reflect on deeds done, but the nascent dawn of new works—the idea, the inspiration, of a history ever beginning anew. And history is precisely the laboratory for its continuous experiments, where it puts the efficacy of its constructions to the proof. The truth of a philosophic system cannot be decided by *a priori* reasoning, but lies in its concrete, historical function, in its action as the creative potency of a new rational harmony of the forces working in the world. Its truth is decided on the battlefields where the banners of old and new ideas are waving, and their age-long conflicts are composed in unpredictable agreements; in the revolutions which give birth to new civilisations; in the daily struggles, to which each man brings his whole thought, whether they be bloodless arguments or bloody encounters; in the book that works on souls and transfigures them, as in the ship that, crossing the oceans, brings continents together; in the parliamentary assemblies as in the fields and workshops;

in political vicissitudes as in economic relations; in the public government of the State as in the intimate sanctuary of the family—wherever a soul acts through the impulse of an idea. Every instant of history in its " concordia discors " fulfils the perennial experiment of our philosophic conceptions, which are relatively true only in the measure in which they make their efficacy felt in this fluid agreement of forces in conflict, which recomposes itself in forms that are always new.

Thus rationality is not a fixed system of immutable principles and essences, not a persistence of abstract identities, but a concrete agreement constructed in its various degrees by the same process that engenders the life of history. It can assume an infinity of modes and forms that cannot and must not be predetermined. If rationality is thus envisaged, the craving that leads to irrationalism, the need to save the freedom of the spirit and the concreteness of experience, is satisfied. In fact, the whole fertile wealth of our intuitions and the possibility of ever new creations remain. And only so can the age-long antinomy between freedom and predestination, the product of the static and intellectualistic mode of conceiving rationality, be resolved. Only so is rationality in its dynamism equated to that infinite Power of creation that was the new word of Christianity. There is no system of intelligibles motionlessly present to the Mind of God. If that were so He would be the prisoner of His own eternal Thought. There would be no sense in speaking of creation, for in that Thought everything would have been already given. Divine Reason is not enclosed in any fixed order, but realises itself in infinite orders in the process of history, which is the work of at once man and God in intimate spiritual collaboration. And Providence is not a preformed design, but, in every instant of life, the creation of a new design that co-ordinates—God always present and working—our own human designs.

CAUSALITY IN NATURE

By MAX PLANCK

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THE recent developments in physics have shown that the high expectations of a deepening of the knowledge of nature which, in a certain degree, were rightly raised by the brilliant successes of physical research, must in essential points be reduced. In particular, the law of causality in its usual classical formulation can no longer generally be applied, because it has definitely been found to fail to apply in the world of atomic phenomena. It is necessary, therefore, that everyone who is interested in the meaning and importance of physical research should make a new examination of the peculiar characteristics of physical law, and in particular should strive to penetrate more deeply towards the roots of the concept of causality.

Today it is no longer possible to regard, with Kant, the law of causality as an expression of inviolable regulation which inheres in events, and is therefore a necessary framework in which experience comes to us, and without which experience is incomprehensible. In Kant's view certain modes of thought or categories are necessary for the conceiving of our experiences, and will remain the same for all time, but this does not assert anything about the nature of single categories. Kant regarded the axioms of Euclidean geometry as having the status of a category, and it is now known that not only is this category capable of extension, but even is in need of extension. Physicists therefore are, consequently, now extremely cautious of accepting the finality of all such modes of thought and categories. In order to avoid prejudice we will bind ourselves by no dangerous assumptions and will therefore look for a reliable starting-point for the introduction of the concept of causality.

In speaking of a causal link between two successive events we mean a certain connection, subject to law, between the two events, of which the earlier event is called the cause and the latter one the effect. But the question is, in what does this particular kind of connection consist? Is there any infallible sign proving a certain event occurring in nature to be causally conditioned by another?

This question is as old as natural science, as old even as the whole of science, and that it continually arises proves it has not yet been finally answered. This unsatisfactory situation is mitigated by the fact that it could not be otherwise. For the expectation that the concept of causality could from the beginning have been formulated with complete precision and then applied to natural phenomena to see whether it fitted them, would in earlier times have appeared naïve, and today the development of exact research would make such an expectation foolish. In natural science and other sciences we do not start with fundamental notions and then search for their realization in the world around us, but on the contrary proceed from an examination of the world to the formulation of fundamental notions. As humans all of us through birth are set in the middle of a world in process of development. We are not previously prepared or informed of its nature, and in order to find our way in this life into which we have been obtruded we deal with our personal experiences as well as we can, while we form, with the help of the mental gifts with which we were born, certain concepts useful in describing the experience we have had, and therefore the experience which we shall have to expect. Much free-will and uncertainty obviously creep in with this procedure, as is proved by innumerable events in every branch of science. Even in mathematics, the most exact of the sciences, the origin and nature of the fundamental ideas are disputed more intensively than ever before. If this can happen with mathematical ideas, nobody should expect that the concept of causality in nature can easily be settled in a manner accepted as valid for all times and states of knowledge.

The never-abated and indeed now greatly increased interest

of the thoughtful in the question of the nature and validity of the law of causality suggests that the concept of causality deals with something very fundamental, with something independent of human minds and intelligence which has its roots deep in a reality not susceptible of direct scientific examination. Few would doubt that if the earth and all its inhabitants suddenly perished the cosmic process would continue to obey causal laws, even if no one were there to observe the fact. Be that as it may, our only method of apprehending the essence of causality consists in studying the world of fact given to us—that is, in studying our experiences. By profound consideration and generalization, and the utmost elimination of all admixture of anthropomorphical elements, we may slowly approach an objective concept of causality.

The numerous investigations hitherto undertaken concerning this question show that the surest approach to a clear answer is obtained by connecting the question with the possibility of making correct predictions of the future. Indeed, for proving that any two events are causally connected there is no more unobjectionable means than that which consists in showing that from the occurrence of one event the occurrence of the other event can always be concluded in advance. That was already known to the farmer, who demonstrated *ad oculos* to the incredulous peasants the causal connection between artificial manure and fertility of soil. The peasants refused to believe that the lush growth of clover on the farmer's field was due to artificial manure, and sought for other reasons. So the farmer had certain narrow furrows ploughed on his field; then he shaped them into letters and manured them profusely, so that after the shooting up of the seed the following sentence was legible in distinct clover-writing: "This strip of land has been manured with gypsum."

As a starting-point for all further considerations I will therefore use the following proposition, applicable also beyond the domain of physics: *An event is causally conditioned if it can be predicted with certainty.* Thereby, of course, I only wish to say that the possibility of making a

correct prediction for the future forms an infallible criterion for the existence of a causal connection, not by any means that the two mean one and the same thing. I need only recall the well-known example, that in the daytime we are quite able with certainty to predict the advent of night, yet day is not the cause of night. But on the other hand we often assume the existence of a causal connection in cases where there is no possibility at all of a correct prediction. Think of the weather forecasts! The unreliability of weather prophets has become proverbial; and yet there is no trained meteorologist who does not look upon the occurrences in the atmosphere as causally determined. Thus we see that the original proposition chosen has only a provisional character. To reach the essence of the concept of causality we must sift matters more minutely.

In the case of weather forecasts we may easily suppose that their unreliability is only conditioned by the size and the complicated nature of the object under consideration—the atmosphere. If we take only a small quantity of it, say a litre of air, we shall far more probably be able to make correct predictions as to its behaviour under external influences, such as compression, heat, moisture and the like. We know certain physical laws which enable us to predict more or less positively the results of the corresponding measurements, such as increase of pressure, increase of temperature, or condensation.

On closer observation, however, we arrive at a very remarkable conclusion. Even if we choose ever so simple conditions and use ever such delicate measuring instruments, we shall never succeed in calculating in advance the results of our measurement with absolute accuracy; that is to say, not so accurately that it will agree with the measured number to the last decimal place. There always remains some residuum of inaccuracy, in contrast with purely mathematical calculations such as those of $\sqrt{2}$ and π, which can be stated exactly to any number of decimal places. And what applies to mechanical and thermal phenomena is valid for all regions in physics, including electrical and optical phenomena.

Our experiences therefore compel us to recognize the following statement as a given and established fact: *In not a*

single instance is it possible to predict a physical event exactly.

On placing this fact side by side with the proposition, which served as our starting-point, that an event is causally conditioned if it can be predicted with certainty, we are confronted by a vexatious but unavoidable dilemma. *Either* we stick to the wording of the original proposition, so that there is not a single instance in nature in which a causal connection can be asserted, *or* we make room for the assumption of a strict causality, then we are compelled to subject our original proposition to a certain modification.

There are nowadays a number of physicists and philosophers who have decided in favour of the first alternative; I will call them the indeterminists. According to them there is absolutely no real causality in nature—no strict law. It is only an illusion given us by the appearance of certain rules which are never absolutely valid, although they are often very approximately so. On principle the indeterminist seeks a root of a statistical kind for every physical law, for gravitation, and for electrical attraction. For him they are all laws of probability, only relating to mean values from numerous homogeneous observations, and possessing only approximate validity for single observations, always admitting, therefore, of exceptions.

The dependence of the pressure of a gas on the surrounding sides of a vessel on its density and temperature is a good example for such a statistical law. The pressure is evoked by the impact of the random-flying molecules of gas against the sides of the vessel. The summation of the effects of these dynamical effects gives the result that the pressure on the sides of the vessel is nearly proportional to the density of the gas and the mean square of the speed of the molecules, which is in satisfactory agreement with experimental measurements, if one regards the temperature as a measure of the speed of the molecules.

This theory is directly confirmed by investigating the fluctuations with time in the pressure on a very small portion of the sides of the vessel. If we observe a very small part of a

side of the vessel, say the billionth of a square millimetre, a long time may pass before a molecule hits it. But it may also happen that two or even three molecules may come soon after each other. Under these conditions there is not a constant but a fluctuating gas pressure. The simple law of pressure is valid only for large areas of the sides of the vessel, upon which a vast number of molecules impinge, so that irregularities cancel out among themselves.

Since molecules by their impacts always disturb mobile bodies when they impinge on them, they manifest themselves in the phenomenon first described by Brown and named after him. Fine particles suspended in liquids may be observed under a powerful microscope to oscillate continually. They are pushed to and fro by the molecules of liquid which impinge on them. A similar effect is observed with very sensitive balances for measuring weight. These never come to complete rest, but perform incessantly slight irregular oscillations about the position of equilibrium. The phenomena of radioactivity provide a further example of statistical law. Owing to its spontaneous disintegration, a radioactive substance incessantly emits a multitude of positively and negatively charged particles. For longer periods of time one may speak of a steady rate of emission, but for shorter periods comparable with the time between the emission of constructive particles the emission is completely irregular.

As in the cases of the laws of gases and radioactivity, the indeterminists wish to attribute all other physical laws ultimately to chance. For them nature is governed by statistics alone, and their aim is to base physics on the calculus of probability.

But in fact the science of physics has hitherto developed on the opposite basis. It has chosen the *second* of the two alternatives: that is to say, in order to be able quite strictly to maintain the law of causality, it has slightly modified the starting-point, which was that an event was causally conditioned if it could be safely predicted. The modification consists in using the word "event" in a slightly altered sense. It is not to one

single actual measurement, always containing casual and unessential elements, that the theoretical physicist gives the name of event. He reserves this name to an imagined process, going on in another world: we will call it the "physical world-picture," which is substituted for the actual one given by our senses and by measuring instruments acting as a kind of refined sense. The physical world-picture is a mental construction, arbitrary to a certain extent; an idealization, created for the purpose of escaping from the uncertainty which inheres in every individual measurement, and of becoming able to establish sharply defined conceptual relations.

In physics, therefore, all measurable quantities—lengths, intervals of time, masses, charges and the rest—have a double meaning, according as to whether we consider them as given directly by measurement or as transferred into the physical world-picture. In the first meaning such quantities can only be defined inaccurately, and can therefore never be represented by precise numbers. But in the physical world-picture they stand for definite mathematical symbols, which can be operated with according to strict rules. If in physics we make use of a trigonometric equation for calculating the height of a tower, then in speaking of the height we mean quite a definite thing, a well-defined quantity. Yet the actual measurement of the height does not furnish a definite quantity. Consequently the so-called true height of the tower is a different thing from the measured height. Exactly the same argument applies to the frequency of vibration of a pendulum or to the brightness of an incandescent lamp. Likewise every universal constant—for instance, the speed of light in empty space or vacuum, or the charge on an electron—is a different thing from the actually measured quantities. In the first meaning it is absolutely precisely, but in the second only inexactly, defined. The clear and logical distinction between the magnitudes and quantities of the world of sense and the similarly named magnitudes and quantities of the physical world-picture is absolutely indispensable for the clarifying of conceptions. Without this distinction a discussion about these questions is futile.

Therefore it is wrong to state, as some do, that the world-picture of physics contains or ought to contain only directly observable quantities. On the contrary, directly observable quantities do not appear at all in the world-picture. It contains nothing but symbols. Besides, there are always in the world-picture elements which for the world of senses have only a very indirect significance or none at all, such as ether-waves, partial vibrations, co-ordinate systems and the like. Such elements at first act as ballast, but they are put up with in view of the decided advantage afforded by the introduction of the mental world-picture. This advantage is that the world-picture enables us to carry through a strict determinism.

To be sure, the world-picture always remains an auxiliary conception: what we are eventually concerned with is, of course, the events in the world of the senses and their approximately correct forecasting, which in classical theory is effectuated in the following manner. First, an object of the world of the senses, say a system of material bodies in any measured state, is symbolized—that is to say, transferred into the world-picture. In this way a definite physical system in a definite initial state is obtained. In like manner the influences which are subsequently exerted upon the object from the outside are replaced by corresponding symbols in the framework of the world-picture. Thus we are provided with the external forces acting on the systems, or with the boundary conditions. By these data the behaviour of the system is for all time unambiguously defined and can be calculated with absolute accuracy from the differential equations of the theory. Thus the co-ordinates and the momenta of all particles of the system result in quite definite functions of time. Now if for any later time we transfer back into the world of the sense the symbols used for the world-picture, we obtain a connection between a later event in the world of sense and an earlier event in the world of sense. This connection can then be utilized for the approximate prediction of the later event.

To summarize: While in the world of sense the prediction of an event is always affected by something of an uncertainty,

in the physical world-picture all events follow certain definable laws; they are strictly determined causally. Therefore the introduction of the world-picture reduces the uncertainty in the prediction of an event in the world of sense, to the uncertainty of the translation of the event from the world of sense to the world-picture and *vice versa*. Herein lies the significance of the physical world-picture.

In classical theory, without much bothering about this uncertainty, attention was concentrated on the elaboration of the causal view of what is going on in the ideal world-picture—that is, how it has achieved its great successes. In particular, it has succeeded in finding a satisfactory interpretation for the irregular fluctuations mentioned above, which correspond to the pressure of a gas or to the Brownian movement—an interpretation that was based on the assumption of strict causality. For the indeterminists no real problem existed here. As they seek irregularity behind every rule, statistical law is what immediately satisfied them. Therefore they content themselves with the assumption that the collision of two individual molecules, as well as the impact of a molecule on the side of the vessel, occurs only to statistical laws. However, there is as little conclusive reason for such an assumption as there is for assuming that, because the electrons gather on the surface in a charged conductor, the charge of an individual electron must be on its surface too. On the other hand, the determinists, who conversely seek a rule behind every irregularity, were led to the task of building up a theory of the gas laws on the assumption that the collision of two individual molecules is strictly conditioned causally. The achievement of this task is the life-work of the great physicist Ludwig Boltzmann. It forms one of the greatest triumphs of theoretical research. For this theory leads to the statement—confirmed by measurements—that the average energy of the fluctuations around the position of equilibrium is proportional to the absolute temperature. And further, from the measurement of such oscillations—for instance, those of an extremely sensitive torsion-balance—this theory makes possible a remarkably accurate calcu-

lation of the absolute number and mass of the colliding molecules.

In view of these and other great successes, reasonable hope prevailed that the world-picture of classical physics would on the whole be equal to its task, and that the uncertainties remaining after the transfer into and from the world of the senses would lose their importance as experimental methods improved in refinement. But with one stroke this hope has for all time been destroyed by the appearance of the elementary quantum of action.

As the quantum theory started from a study of the phenomena of heat and light, these may be considered first. It has been discovered from a variety of evidence that the energy in a ray of light of any particular colour is not transmitted continuously, but in single particles, named photons, whose size is dependent only on the colour of the light, and which fly forth in different directions from the source with the speed of light. This is in perfect agreement with the early corpuscular theory of light formulated by Newton. The photons ordinarily succeed each other so swiftly that the light which they constitute seems to arrive as a continuous stream; but if, through growing distance from the source, the light becomes feebler and feebler, the photons become more and more separated, as a jet of water breaks into a stream of drops of a certain size. It is characteristic of radiation that it diminishes in intensity, not by a diminution of the energy of the constituent photons, but by an increasing scarcity of photons.

It is easy to see that the application of the notion of causality to such phenomena leads to serious difficulties. Let us consider, for instance, the behaviour of a ray of light which comes from a certain direction and impinges on a polished glass plate. A part of the light may be reflected and another part, perhaps three times as much, may be transmitted. We know by experiment that this proportion is not affected by the intensity of the light and is therefore independent of the number of photons in the ray. If very many photons strike the plate, say one million, a quarter of a million are reflected

and three-quarters of a million are transmitted. But what will happen if a very feeble ray containing only one photon strikes the plate? This presents a serious dilemma, because it is impossible to say whether it should be reflected or transmitted.

But there is worse to follow. In the previous example a solution might be found in the assumption that the uncertainty of the direction of the photon is due to ignorance of some unknown influence controlling the behaviour of the photon. The following example seems, however, to be quite hopeless. It is evident that certain colours may be preferably reflected and others preferably transmitted, because when white light falls on the glass plate the plate appears coloured, not only in the reflected, but also in the transmitted light. The classical wave-theory of light has completely explained that the light reflected at the front side of the plate interferes with the light reflected from the back side—*i.e.*, that these two reflected rays weaken each other according to the coincidence of a wave-crest of one ray with a wave-trough of the other ray. As the wave-length for different colours is different, this effect varies according to the colour. Experiment has shown that the observed variations are strictly in agreement with the calculated variations. Now what happens if a single photon strikes the glass plate? The photon must interfere with itself, and as it is indivisible that is, on classical views, impossible. Evidently these quantum phenomena are quite inexplicable in terms of the wave-theory of light.

The position concerning the quantum theory in mechanics is not different from that in light. For the smallest quanta of mass, the electrons, are like photons in that they can interfere with themselves. An electron of a certain speed exactly corresponds in this connection to a photon of a certain colour. When it falls upon a crystal plate it is preferably reflected or transmitted, and the detailed results arise from a consideration of the wave-lengths corresponding to its energy. Therefore the question which way the electron shall go, just as in the case of the photon, is not only an unsolved, but an insoluble, problem.

The principal difficulty, which is concerned with the determination of the place of an electron moving with a certain speed, finds its general expression in the uncertainty relation formulated by Heisenberg, which is characteristic of quantum physics. It states that the more accurately the position in space is measured, the more inaccurate is the measurement of the speed, and *vice-versa.* This is explained in the following way. We are able to measure the position of a flying electron only when we can see it, and therefore we must illuminate it—*i.e.*, we must let light fall upon it. But the light which falls on the electron gives it a shock and changes its velocity in an uncontrollable manner. The more accurately the place of the electron is to be measured, the shorter must be the waves of the illuminating light, and hence the greater the shock, and therefore the greater the uncertainty of the measurement of the speed.

It stands to reason that this statement makes it on principle impossible to transfer with any accuracy into the world of the senses the simultaneous values of co-ordinates and momenta which play the predominant part in the world of classical physics. For the strictly causal view of the world this fact raises a difficulty, which has already led some indeterminists to affirm that the law of causality in physics is definitely disproved. However, on closer consideration this conclusion, which is due to confusion of the world-picture with the world of sense, must be called at least premature. For there is at hand, for overcoming this difficulty, a means which has often done excellent service in similar cases. It is the assumption that the question as to the simultaneous values of the co-ordinates and of the momenta of the particle has no meaning in physics. The law of causality must not be blamed for the impossibility of answering a meaningless question. The blame must rather be laid on the assumptions which have led to the putting of that question—that is to say, on the assumed structure of the physical world-picture. And as the classical world-picture has failed, it must be replaced by another.

In fact, this has been done. The new world-picture of

quantum physics has arisen from the desire to render possible the accomplishment of a strict determinism in spite of the existence of the quantum of action. For this end the material particle, which has hitherto formed the primary component of the world-picture, has had to be divested of its elementary character: it has been dissolved into a system of material waves, which form the elements of the new mental picture of the world.

The world-picture given by the quantum physics stands in about the same relation to that of classical physics as the wave optics of Huygens to the corpuscular or ray optics of Newton. As the latter was sufficient for many cases, but failed in others, the classical or corpuscular mechanics appears as a special case of the more general wave-mechanics. Instead of the material point we have an infinitely small packet of waves—*i.e.*, a numerous system of waves which interfere with each other in such a way that they cancel themselves everywhere in space except when the material point is to be found.

In general the laws of wave-mechanics are, as everybody knows, quite different from those applying to particles in classical mechanics. But the most important point is that the function which is characteristic for the material waves, the wave function or the probability function—the name is irrelevant here—is completely determined for all places and times by the initial conditions and the boundary conditions. We can calculate it by quite definite rules, employing either Schrödinger's operators or Heisenberg's matrices or Dirac's q-numbers.

The introduction of the wave function also solved the problem of how a single electron behaves when it strikes a crystal plate; whether it is reflected or whether it penetrates the plate. The electron cannot divide, but each of the waves acting in its place is able to divide, so that there is a possibility of interference of the parts of the waves, and this interference proceeds according to definite laws.

Thus we see that the world-picture in quantum physics is governed by the same rigorous determinism which rules classical physics. It is only that the symbols are different,

and that we operate with other rules of calculation. Accordingly in quantum physics, as formerly in classical physics, the uncertainty in the prediction of events of the world of sense is reduced to the uncertainty of the connection between the world-picture and the world of sense; that is to say, to the uncertainty of the translation of the symbols of the world-picture into the world of sense and *vice-versa.* The fact that this double uncertainty is put up with forms the most impressive proof of the importance of the task of maintaining determinism in the world-picture.

To the critical judge the price, paid for the salvation of the strict law of causality, must seem indeed high. Yet but a superficial glance enables us to recognize how very far in quantum physics the world-picture has diverged from the world of the senses, and how much more difficult it is to transfer an event from the world-picture to the world of the senses, or *vice-versa,* in quantum physics than it formerly was in classical physics. In classical physics the meaning of every symbol was immediately comprehensible: the position, the velocity, the energy of a particle could be stated more or less directly from the measurements. There was no evident reason for not assuming that one should be able to reduce the remaining uncertainty below any limit, as the refinement of experimental methods progressed. On the other hand, in quantum mechanics the wave function yields no means whatever whereby this function can be interpreted directly in the world of sense. There should be no delusion concerning the name "wave," however suitable and illustratively chosen, as the meaning of this word in quantum physics is entirely different from that in classical physics. In classical physics a wave describes a certain physical phenomenon, a perceptible movement or vibrating field open to direct observation. But in quantum physics it describes only the probability for the existence of a certain condition. For that which is divided when a photon or electron impinges on a crystal plate to produce the interference phenomena is not the photon or electron itself, but only the probability for the existence of the individual photon or electron. This quantity represents a

quite certain number of photons or electrons only if extremely many impinge on the plate.

This circumstance has again incited the indeterminists to an attack upon the law of causality. And this time the attack seems to promise a positive success; for from all measurements nothing more than a statistical significance of the wave function can be deduced. But again the same loophole for escape is open to champions of strict causality. They assume that the question as to the significance of a definite symbol in the world of quantum physics—for instance, a material wave —has no definite meaning, as long as we are not at the same time told how to ascertain this meaning—not told in what condition is the special instrument which is employed for transferring the symbol into the world of sense. We therefore also speak of the causal effect of this instrument. Thereby we imply that the inaccuracy under discussion is at least in part conditioned by the fact that the amount of the quantity to be measured depends in a certain manner, subject to law, on the nature of the measuring process.

In fact, every measurement, whatever method may be used, brings in itself a more or less strong perturbation of the phenomena to be measured, as we have already seen in the previous example of flying electrons, whose path is disturbed by the light indispensable for observation and is disturbed the more as the lighting is made more precise. Thus if a certain material wave corresponds on one occasion with one process in the world of sense and on another occasion with another, the question of its sensory meaning is to be answered, not by observation of it alone, but only by observation of the reciprocal relation between it and the measuring instrument.

With this auxiliary assumption the whole question has been led into channels the further course of which still remains dark. For now the indeterminists are justified in putting forward the question whether any sensible meaning can be attributed to the idea that the measuring instrument should exert a causal influence on the process to be measured; for any attempt to test this influence would require new measurements, which would involve a new causal interfer-

ence and would therefore bring a new feature of uncertainty into the problem. Therefore it seems to be impossible in principle to divide the "process in itself" from the instrument with which it has been measured.

And yet this objection does not finish the matter. For, as every experimental physicist knows, there are not only direct but also indirect testing methods. In many cases the latter have done good service where the former had failed. Above all, I wish to oppose the now widespread and seemingly plausible opinion that a question in physics is only worth investigation if from the outset the fact that it admits of a definite answer is established. If the physicists had always followed this precept, the celebrated experiment of Michelson and Morley on the measurement of the so-called absolute velocity of the earth would never have been made. We should then perhaps not even today be in possession of the theory of relativity. So our efforts to ascertain the absolute velocity of the earth have proved exceedingly fruitful for science, although nowadays the question itself is almost universally considered to be meaningless. Then are we not justified in expecting even much greater profit from investigating the problem of causality, the roots of which have certainly not been reached hitherto—a problem quite pre-eminent in its fertilizing influence on research?

But how shall we come to a decision? Evidently there is nothing for it but to take one's choice between the opposing standpoints, to adopt one, and then to see whether from this starting-point we attain valuable or useless results. In this respect we must welcome the fact that the physicists who are interested in this subject are divided in two camps, one inclining to determinism, the other to indeterminism. As far as I see, the latter are at present in the majority. But it is hard to tell, and the situation may easily change in the course of time. In between there seems to be room for a third party, occupying an intermediate position. They attribute to certain concepts, such as electrical attraction and gravitation, an immediate significance and a strict rule of law, while ascribing to other concepts, such as the light-wave and the particle-

wave, only a statistical significance for the world of sense. This notion, however, appears at the outset rather unsatisfactory on account of its want of uniformity. So I shall leave it aside and confine myself to the elucidation of the two absolutely logical standpoints.

The indeterminist's yearning after knowledge is satisfied by the statement that the wave function of quantum physics is only a probability scheme; for him there is no further question to put. Also with the radioactive processes he is satisfied by the statement that, for instance, in any radioactive accumulation a certain average number of atoms disintegrate every second, but he does not ask why one atom disintegrates just now and a neighbouring atom perhaps a thousand years later. On the other hand, he looks upon a definite law of nature, such as Coulomb's law of electrical attraction, as an unsolved problem. He cannot content himself with Coulomb's law of force or potential, but must try to find exceptions. He will not be satisfied unless he succeeds in establishing what the probability is that the electrical force will diverge from Coulomb's law to any specified extent.

The determinist takes the opposite view in all these matters. He is quite content to look upon Coulomb's law as an ultimate and fundamental law of nature. The interpretation of the wave function as a probability function he will only admit as long as no account is taken of the particular apparatus with which the wave is generated or analyzed. He seeks relations strictly subject to law between what is going on in the bodies that interact with the wave and the form of the wave function. For this purpose he is, of course, obliged to begin by making the measuring apparatus as well as the wave function the object of his research. That is to say, he must transfer into his world-picture the whole experimental arrangement for generating the material waves—for instance, the high-potential battery, incandescent wire, or radioactive substance—and also the whole of the measuring apparatus, such as the photographic plate, ionization chamber, or Geiger counter, with all that is going on in them; he must treat all these objects together as one single system, as a closed unity.

This, of course, is not sufficient to solve the problem, which on the contrary has become even more complicated. For since one is allowed neither to divide the total system nor to expose it to any interference from outside, lest it should lose its original character, no direct test whatever is feasible. On the other hand, it now becomes possible to set up certain hypotheses of a new kind with regard to the internal occurrences, and then to examine their consequences. The future will show whether we are able to advance in this way; up to now we cannot distinctly discern in what direction progress will be accomplished. But this much may be safely affirmed: the elementary quantum of action sets an objective insuperable limit to the sensitiveness of the physical measuring apparatus at our disposal, which will prevent us for ever from completely causal understanding of the minutest physical processes "in themselves"—*i.e.*, independently of their source and effects.

This really brings us to the end of our considerations. They have shown us that the standpoint even of modern physics does not prevent us from achieving a strictly causal view—the word "causal" being understood in the modified sense explained above—although the necessity for such a view can be proved neither from the outset nor afterwards. Yet even the convinced determinist—and he, perhaps, more than anybody else—is overcome by a scruple which hinders him from being quite satisfied with the interpretation of causality introduced here. For even if we should succeed in further developing the concept of causality on the lines laid down, it would be affected by a grave deficiency. One might suppose that a relation of so deep a significance as the causal connection between two successive events would in its essence be independent of the human mind which considers it. The reverse is true. At the outset we had to attach the concept of causality to the human intellect, with reference to the capability of predicting an event; furthermore, we were not able to enforce the adoption of the deterministic view otherwise than by substituting for the given world of our senses the physical world-picture. The latter is a creation of human imagination

of a provisional and changeable character. Anthropomorphisms of that sort are ill-suited to form a fundamental physical concept. So the question arises whether there is no way of giving the concept of causality a deeper significance by divesting it as much as possible of its anthropomorphic character and by making it independent of the introduction of an artefact, such as the physical world-picture, but directly connected with the experiences in the world of sense. We must, of course, retain our original proposition, that an event is causally conditioned if it can be safely predicted; otherwise we shall lose our only foothold. But we must also adhere to the second proposition, that in not a single case is it possible to predict an event exactly. It then follows, as before, that in order to be able to speak of causality in nature we must apply some modification to the first statement. So far everything remains as it was. But the modification we had applied above can be replaced by one of quite a different kind, in one sense quite an opposite modification.

What we modified here was the object of prediction, the event. We did not refer the events to the immediately given world of the senses, but to the fictitious world-picture. Thus we were able accurately to determine the events. But instead of the objects we may modify the subject of prediction, the predicting mind. For every prediction necessitates the existence of a predictor. In the following we shall therefore limit our attention to the predicting subject, and look upon the immediately given events of the world of sense as the object of prediction, without introducing an artificial world-picture.

It is obvious that the certainty of the prediction depends in a high degree upon the individuality of the predictor. Let us again refer to weather forecasts. It is evident that it makes a great difference who provides us with the forecast for tomorrow—whether it is an ignorant person, who knows nothing about today's atmospheric pressure, direction of the wind, atmospheric temperature and humidity, or a practical farmer, who has noted all these data and has a wide experience, or again a scientifically trained meteorologist, who besides the local data has at his disposal numerous weather-

charts from all parts with exact information. With each of these successive prophets the uncertainty of the prediction is more and more diminished. It is therefore an obvious thought to assume that an ideal mind, apprehending everywhere all the physical occurrences of today in their minutest points, should be able to predict with absolute accuracy the weather of tomorrow in all its details. And the same argument can be applied to every other prediction of physical events.

Such an assumption means an extrapolation, a generalization, which can neither be maintained by a logical conclusion nor refuted *a priori*. It must therefore not be judged according to its truth, but rather according to the value that is inherent in it. In the light of this view, the actual impossibility of accurately predicting an event in even one single case, either from the standpoint of classical physics or from that of quantum physics, is a natural consequence of the circumstance that man with his senses and his measuring instruments is a part of nature. He is subject to her laws and cannot escape from her, while such a tie does not exist for the ideal mind.

The objection that this ideal mind is only a product of our thoughts, and that our thinking brain also consists of atoms following physical laws, is not able to withstand a closer test. For it is indubitable that our thoughts can lead us beyond every law of nature known to us, and that we are able to imagine relations which transcend the realm of physics. He who would assert that the ideal mind could exist only in human thoughts, and would disappear from life when the men that think the thoughts disappear, must also assert that the sun, like the whole of the external world, can exist only in our minds as the only source of scientific knowledge, while every reasonable man is convinced that the sun, even if the whole of mankind were extinguished, would not in the least lose its illuminating power. We believe in the existence of a real external world, though it withholds itself from direct observation. In the same way nothing prevents us from believing in the existence of an ideal mind, though it will never make itself an object of scientific research.

We must not consider the ideal mind akin to us, and must not demand of it how it procures the knowledge enabling the exact prediction of future events. For the inquisitive questioner might easily, like Faust, be awed by the answer: "Thou'rt like the spirit which thou comprehendest, not me!" And if the questioner nevertheless remains obdurate and declares that the notion of an ideal mind, if not illogical, is yet empty and superfluous, he must be met with these arguments: Not all statements eluding logical reasoning are scientifically valueless, and such a short-sighted formalism chokes up the source at which men like Galilei, Kepler, Newton and many other great physicists have slaked their scientific thirst for knowledge. For all these men, consciously or unconsciously, the devotion to science was a matter of faith, of unwavering faith in a rational scheme of the universe.

It is true this faith can be forced upon nobody, just as one cannot command truth or forbid error. But the simple fact that up to a certain degree we are able to subject future natural events to our thoughts and to guide them at our will would remain a complete riddle if it did not at least point to the existence of a certain harmony between the outer world and the human mind. And the question to what depths one imagines the sphere of this harmony to be extended is only of secondary importance. In any case, the completest harmony and therewith the strictest causality rests in the assumption of an ideal mind, which sees through the laws of nature besides the phenomena of the intellectual life, down to the minutest detail in present, past and future.

But how does this affect the freedom of the human will? Will this not be abolished, and man therewith degraded to a bloodless automaton? This problem is too near and too important to be dismissed without a few words of discussion, although I have already had occasion to define my position regarding it. In my opinion there exists not the slightest contradiction between the reign of a strict causality, as in the views here expounded, and the freedom of the human will.

The law of causality and the freedom of the will refer to quite different questions. While, as we have seen, the understanding of a strict causality in the world's process needs the assumption of an ideal all-seeing mind, the question whether the will is free or not is an affair only of self-consciousness, thus can be decided only by the self. The concept of free-will means only that man himself feels inwardly and mentally free, and whether this is the case only he himself can know. That is not in contradiction with the view that the motives of his will can be thoroughly discerned by an ideal mind. He who feels himself restricted in his moral dignity by such an idea forgets the enormous superiority of the ideal mind over his own intelligence.

The most remarkable proof of the independence of one's will from the law of causality is seen when, in order to increase self-knowledge, one tries to predetermine, with the help of the law of causality, the activities and motions of one's will. Such an attempt is from the beginning bound to fail, because every application of the law of causality to the will would produce knowledge of the will which would itself act as a motive and thereby always change the result. Therefore it is thoroughly mistaken to say that the impossibility of causally predetermining our activities is due to lack of understanding which perhaps later, through a tremendous increase of intelligence, would be removed. That would correspond to the assertion in physics that the impossibility of exactly determining at the same time the position and speed of an electron is due to the incompleteness of the observations. No, the impossibility of deriving our future activities purely causally is not due to lack of understanding, but to the simple condition that no method which transforms an object is suitable for examining it. The thinking man, therefore, never can make the authoritative decision through the law of causality, but only through a quite different law, the moral law, which grows in a special ground and is not to be apprehended by scientific methods alone. Scientific thinking requires always a wide and sharp difference between the thinking subject and the studied object, and this distance will be guaranteed best

by the assumption of an ideal mind which can be considered only as a subject and never as an object.

May not the prohibition against the ideal mind an object of thought involve an unsatisfactory renunciation, so that the accomplishment of a strict determinism is too dearly purchased? However this may be, the price is less than the indeterminist must pay for his view of the world, as he must cease at a much earlier point his quest for knowledge, because he must renounce from the first the possibility of certain laws valid in special cases, a degree of resignation which is so astonishing that one would have to ask why determinism nowadays has so many followers among the physicists. If I am not mistaken, the explanation lies in the psychological sphere. When a new great idea appears in science it is tested in all directions, and if it is proved to be fruitful one tries to make it the foundation of a comprehensive and closed system of ideas; thus it was with the theory of relativity, and now it is with the quantum theory. As quantum physics at present culminates in the wave function, one tries to give this a final significance. As the wave function has the significance only of a measure of probability, one tries to make the question of probability the final, deepest problem, and therewith makes the concept of probability the foundation of the whole of physics.

I do not believe that in the future these questions will ever be solved. For if in spiritual spheres, whose laws possess even more the character of probability, no single event can be exactly determined if the causal source is not made clear, the problem of causality is much less likely to be eliminated from natural science.

The law of causality is neither right nor wrong, it can be neither generally proved nor generally disproved. It is rather a heuristic principle, a sign-post, and to my mind the most valuable sign-post we possess, to guide us in the motley confusion of events and to show us the direction in which scientific research must advance in order to attain fruitful results. As the law of causality immediately seizes the awakening soul of the child and causes him indefatigably to ask "Why?"

so it accompanies the investigator through his whole life and incessantly sets him new problems. For science does not mean contemplative rest in the possession of sure knowledge; it means untiring work and steadily advancing development towards an aim which we are able to imagine but never to reach intellectually.

[Part of the argument in this essay is also contained in the "Guthrie Lecture" by Professor Planck, delivered before the Physical Society in London on June 17th, 1932, and which was published in Volume 44, Part 5 (1932), of the Proceedings of the Physical Society.]

PHILOSOPHY AND CONTEMPORARY SCIENCE

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MODERN scientific developments have had less direct influence upon the character, as opposed to the matter, of philosophical thought than is commonly supposed. Even recent advances in the maturer sciences like physics and astronomy, revolutionary as they seem, only turn out on inspection to raise problems of the same type as those which have haunted philosophers through the ages. Nevertheless there does seem to be, in our time, a perceptible drift of opinion in philosophy which, whilst not constituting a single unified outlook, yet creates a definite modern temper—and a temper whose cool austerity owes something indirectly to that same quality in scientific thought. It is not easy to describe: but appears in the methods of work of the most outwardly diverse thinkers, and is steadily becoming stronger and more explicit. The product (like so much in our day) of both disillusion and hope, it combines constructive discretion with analytical vigour.

Philosophy, at its best, has always been a more than usually resolute attempt to see the world clearly, and see it whole—an attempt that is to say, to be both critical and constructive. It is in criticism that its more enduring value has lain; but it is construction which has given it prestige. The modern philosophical temper is one which is anxious to earn its unities, to return full value for any prestige which may accrue to it. It is an attitude of mind which is impatient of constructions built on gaps in our knowledge, or achieved by slurring over differences instead of by hard critical endeavour. In short, the emphasis is upon analysis rather than synthesis

—an emphasis so decided that most modern philosophers, even those who believe it may be possible in the future, hold that the time is not yet ripe for anything which could strictly be called metaphysical construction. Not that synthesis is despised. On the contrary, in a world of rapid change like our own, involving the breakdown of earlier unities, new syntheses are a crying need. But that only makes systems more suspect to the philosopher. The objective unities he hopes for must not be mere wish-fulfilments.

A word of explanation is necessary here. Though we may think (in spite of the valued system-building of McTaggart and Alexander) that construction of a strictly philosophical kind is beyond our powers at the present time, it may still be legitimate to attempt something short of this—some bringing together of the separate parts of our knowledge into a possible, if not provable, unity. This would constitute what I should prefer to call 'Synoptic Science' rather than philosophy. If anything of this kind is undertaken, we shall have to distinguish clearly between the two sides of our enterprize—between our critical labours and our constructive hopes. Criticism is individualistic. Construction is complicated by the fact that it is a social, as well as an intellectual, need. Critical power is born of plastic intelligence and bears the mark of its origin, being irresponsible because so responsive to change; it plays light-heartedly over our most cherished cultural systems. Constructive capacity, as used in the past for building unities within which men might live significant lives, is related rather to knowledge than to intelligence; and it is notorious that learning, mere weight of knowledge, is readily harnessed to prejudice or to social necessity.

That is why no synoptic view worth the name can possibly be achieved without including human studies (biological, psychological, sociological) in its scope. These less mature sciences have not, as yet, received the attention they deserve from philosophers, who have been dazzled by the brilliant achievements of physics. Before we can attempt new unities, in a world distracted by partial views and specialist incon-

sequence, this deficiency must be made good. But it may well be that human studies will have to advance much further before we dare entertain any such ambition. It is only through understanding that our animal activities become arts. And perpetual progress in understanding is not, according to Prof. C. D. Broad, inevitable. It is only a possibility—and one which is dependent on our acquiring an adequate knowledge and control of life and mind before the combination of ignorance on these subjects with knowledge of physics and chemistry wrecks our whole social system. "Which of the runners in this very interesting race will win, it is impossible to foretell. But physics and death have a long start over psychology and life."

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The first question we will take up is whether a process involving ideals of explanation which vary from age to age, like fashions, does not vitiate the supposed objective character of science at its source. Everyone now recognizes how all-pervading the act of selection is in scientific work. The scientist chooses his facts; he selects from a range of possible laws; he picks out the hypotheses which best conform to his body of more generalized theories; and finally he comes to realize that there has been an element of choice in his general theory-systems determined by his ideals of explanation. Yet at no stage in this hierarchy does he lose sight of objective reference.

The scientist selects his facts in order to produce the widest possible co-ordinating hypotheses, though the facts must be there to choose from. He chooses also his laws, generally on the grounds of simplicity. Dr. Norman Campbell has brought out this arbitrary element in scientific laws. The 'truth' of a law, according to Dr. Campbell, depends on its fitting the observations; but its 'meaning' comes from the intellectual satisfaction which the particular law chosen affords. The laws of science, then, are chosen from among other possible laws because they fit into theories "the form of which is dictated chiefly by preconceived ideas of what a

theory should be." This introduces a conventional element which often determines the type of laws characterizing an age or a country. Nevertheless, we must not forget that if any law can be shown to be 'untrue' it will at once be rejected, however much 'meaning' it may have. Again, theories and theory-systems, the next stage in this series of levels, are subject to choice. Here, also, we must be careful to avoid assuming that a bare and arbitrary element of personal choice is involved. It is not nearly so simple as that. Dr. Dorothy Wrinch-Nicholson has put the whole matter in regard to these wider and more generalized theories with admirable clearness. She showed that the unusual assumption of a discrete series of states for a physical system, made necessary by quantum theories, can be put in terms of abstract properties of the relation between different states of a single physical system. The choice between a discrete and a continuous series of states can be related to the general characteristics of compact and well-ordered serial relations. As so often happens, she says, the cogency of our objections, which come from the initial strangeness of the ideas, disappears as soon as those objections are stated in their most fundamental terms. "Physical intuitions" she continues, "as to whether very complicated and obscure relations are discrete or compact are clearly, if I may say so, out of place. We have to assume to be true, whatever fits the facts of experience most adequately".

There is thus, at every stage in this series of selective processes, an objective reference which purges the choice of anything arbitrary or personal. Viewing the bewildering range of choice, and the litter of discarded facts, laws, and theory-systems, a critic might exclaim with Mr. Sullivan: "To judge from the history of science, the scientific method is excellent as a means of obtaining plausible conclusions which are always wrong, but hardly as a means of reaching the truth." What the critic would overlook would be the fact that earlier work is never entirely discarded. There is always, as Mr. Sullivan is quick to point out, a part which is incorporated in the next advance. There is a real sense in which

the scientist (to use a phrase coined by Mr. E. M. Forster for a very different purpose) is at an angle with the universe: the man who is always immediately in the wrong because he is ultimately in the right. It must be remembered, however, that the 'ultimately' refers to the end-point of a long series. When Clerk Maxwell constructed his great variety of mechanical analogues he put them forward as being simply scaffolding (a means of readily dealing with the electro-magnetic phenomena to which they are analogous) to be discarded as soon as he had constructed, with its aid, his great generalizations. We must not take the scaffolding too seriously or we shall fail to notice the building: the scaffolding is nothing more than an aid to investigation. We may be forgiven, therefore, if we look with a sceptical eye at the hypostasization of ordering conceptions and at the kaleidoscopic series of world-pictures founded upon them. When, for instance, Sir James Jeans (combining Galileo's conception of God as the great Geometer with the more subjective part of Berkeley's mentalism) talks about the universe as consisting of the thought of a mathematical thinker, we need not take it too literally. It should be accepted only as a suggestive metaphor on the same level as the description of architecture as "frozen music."

We may now turn to the process of abstraction by which we reach our knowledge of structures. Abstraction is an old subject of philosophical debate, of course. But there are reasons for believing that some of the earlier misconceptions can now be avoided, in light of its more deliberate and thoroughgoing employment in recent developments, and of the enormous advance in its technique. It is necessary to deal briefly with the function of abstraction in science because this brings out, as nothing else can, the changed intellectual climate of scientific thought. It seems clear, for instance, that abstraction is neither mere increase in our discrimination of what was already known in a concrete setting; nor bare omission, and hence falsification. For in the first place scientific abstraction gives genuinely new knowledge, supplied in experience but not necessarily of itself expe-

rienced, in such matters as the atomic constitution of bodies, the pre-human history of the earth, and so on. And secondly, scientific abstraction as we have seen it at work, is plainly integrative and not separative in character: its fruits are structural syntheses. Philosophers are alive to this. Prof. Kemp Smith insists that abstraction is more than a methodological device, like a microscope, for studying the partial features of a whole: it is also a recognition of "identities in experience that would otherwise remain in isolation." In abstraction "we are obtaining a knowledge of more than the separate items that make up the real world; we have made a beginning in the task of deciphering what is equally important, its structural pattern." So that besides the enlargement of our sense of possibilities which structural knowledge brings, there is freedom from the hesitations induced by the common but unfounded fears that abstractive analysis might be either falsification or productive of only 'partial' truth. Science has become both less dogmatic and more assured.

That function of the abstract which plays a great part in its fruitfulness has still, however, to be mentioned: namely, that "it makes possible apprehension of its counterpart, the uniquely individual". Increased knowledge of structure brings in its train deeper sensitiveness to individual differences. We do not start with what is individual: that is as much the product of analysis as structure. Now this sense of uniqueness which is, as it were, a by-product of abstraction also acts as a further check on dogmatism. It makes men more alive to what Clerk Maxwell called 'singularities' in nature. Perhaps that is why men of science nowadays can face with equanimity such astonishing possibilities as that causal law may not wholly apply to atomic phenomena, or that electrons may be organisms. If singular points do disturb the deterministic calm of our equations, it need not mean the breakdown of law but only its limitation to other than the unique. No doubt obscurantists will find in this situation a ground of appeal against all forms of law: but the reply to them is, clearly, that our sense of these singu-

larities only advances with, and is dependent upon, increase in the range of our structural knowledge.

We need to be careful not to build upon mere provisional absence of law. The last word has probably not yet been said about quantum theory. And even as it stands, all that the "Principle of Indeterminacy" really asserts is that "a particle may have position or it may have velocity, but it cannot in any exact sense have both." Or to put it in another way, you can only see an electron when it emits light, and it only emits light when it jumps; so that to see where it was you have to make it go elsewhere. Now as Dr. J. E. Turner has pointed out, there is a sense in which a quantity is 'determined' when it is measured. But all the arguments in favour of "free will among atoms" rest on the fallacy of equivocation which substitutes quietly the other sense of 'determined', that in which a quantity is said to be determined when it is caused. Our view on the wider question as to whether everything in the universe is determined will depend on what we take causality to be. But that is a subject which goes beyond atomic physics and involves the nature of law in general. For the moment let us glance at a narrower question: namely, as to whether laws in all the sciences are ultimately reducible to the laws of physics.

It is often stated that materialism has been killed by modern physics. This report is "grossly exaggerated." Materialism is more alive than ever; but it now takes the form of asserting that, in the last resort, the course of nature is determined by the laws of physics. Our view of this will depend on our attitude to the so-called 'emergent' properties of complexes. If these are ultimately irreducible (as Broad, Lloyd Morgan, Smuts and Alexander believe) then the sciences will keep the autonomy they now possess. But again, we must not build on ignorance, on the present gaps in our knowledge. If (as Bertrand Russell and Einstein believe) emergent properties indicate mere scientific incompleteness, then the day may come when the various sciences will finally form a hierarchy in which the primitive concepts

of each science are the derived concepts of the science logically prior to it—a consummation which expresses the working faith of most men of science. I imagine that this question will not be decided until our analysis of the whole notion of emergence and its implications has been carried a good deal further than it has now gone. For the moment we must content ourselves with saying that the world is less of a 'unity' if the first view holds than if the second is true. The one makes the world a plurality of irreducible wholes (as on Lloyd Morgan's view, or Smuts' 'holism'). The other makes it a single system. But even to those who hold the second view, a still more radical doubt supervenes: namely, the doubt as to whether causal laws are anything more than regular sequences between concrete events which induce confident expectations about the behaviour of the universe, but from which we cannot, in the strict logical sense, infer that it is a rational whole. We shall return to this more ultimate question later. For the present, a subsidiary difficulty faces us: namely, the question as to whether the laws of science really do tell us anything about the actual relations in the universe which their structure indicates. Broadly speaking, from sets of laws we can infer a structural order; but structures are generated by relations. Can we find out what the actual generating relations are?

It is clear that one result of the change towards greater abstractness in physics has been to widen the gulf between the structure revealed in its generalizations, and the observations from which they arise and to which they are referred. A number of thinkers hold the view that, in its mature modern form, field physics tells us nothing about the external world but the structure indicated by causal laws. (And the day may come when atomic physics, in the hands of a Dirac, may achieve the same character.) Now logically, our knowledge about structure consists only of the kind of things a blind man could be told about a picture. The mere existence of a given structure (indicated, of course, by physical observations) tells us nothing in itself about the generating relations involved. Consider the world as a four-

dimensional aggregate of point-events and suppose that there exists a system of relations, with the world as field, giving the particular structure indicated by physical laws. Then systems of relations *differing from these* can be found which would nevertheless give the assigned structure. A variety of 'interpretation' is therefore possible, and choice must be made according to some criterion. It was probably considerations of this kind (and overlooked by some of his critics) which led Eddington to suggest that all the laws of classical physics, like the conservation of energy, boil down to nothing but conventions as to measurement; and that our choice depends on that predilection for 'substantial analysis' whose role in the development of physics is now commonly recognized. From that it is but a short step to regarding substance as 'categorial' in the Kantian sense. The footprint we find in the sand is our own.

Apart from the fact that it is very unlikely that we shall return to any form of Kantianism, there is another way open to us of avoiding the conclusion that, because there is an arbitrary choice, nothing objective is known. If our common-sense experience merely leads us up to the structure of law, but not to the relations generating it, then we are as much debarred from knowing the realities of the world as we were when our picture of it was painted in the early bad manner of Eighteenth Century billiard-ball materialism. But we might insist from the outset (as I have hinted before) that we are not standing blindly before the picture. We see it, and do not need an interpreter making arbitrary or conventional choice: that, in short, the realities of the external world including our fellows are, to say the least, as much data of knowledge as the disembodied sense-data and isolated structures which we analyse out of common-sense experience. This is not quite the way taken by Prof. Whitehead in his radical denial of the "bifurcation of nature"; but he does hold that both particulars and structures are equally abstractions from the concrete flux of the "actual occasion". We commit the fallacy of misplaced concreteness if we forget their character as abstractions; yet both are as genuine

characteristics of nature as the flux out of which they arose.

This type of solution amounts in Whitehead to a return to immediate experience in all its concreteness: a step taken, in reaction from difficulties over structural systems, by modern philosophers as widely different as Bergson and Bradley—though for different purposes. The one to replace organized understanding with the way of immediate intuition; the other to avoid the "spectral woof of impalpable abstractions" by a new beginning in "an immediate feeling, a knowing and a being in one." What I had in mind, when speaking of standing before the picture, was not this step, but a return simply to our starting-point in perceptual judgments themselves: and an insistence that statements expressing these form the basis for both (*a*) scientific treatment, and (*b*) philosophical analysis. Science adds to such statements of fact; philosophy, instead of explaining them away, analyses them in the sense of finding out the structure of that to which reference is made if they are true. The sort of view here indicated is the product of several lines of thought. It has special interest for the student of science, in that it induces a more ready acceptance of common-sense fact in all domains—since its aim is to analyse facts, not to justify them. For that reason we must look at it more closely.

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We all make perceptual judgments and express them in statements, such as the proposition (to use Prof. G. E. Moore's example) that "The earth has existed for many years past." Moore suggests that the reason philosophers have so often hesitated to admit that this is the very type of an unambiguous expression, the meaning of which we all know, is that they confuse two senses of the phrase 'we know what it means'. The first of these senses is that we understand the proposition sufficiently to use it in ordinary human discourse. But this is entirely different from the second: that we know what the proposition means in the sense that we are able to give a correct analysis of its meaning.

This distinction is fundamental in Moore's thought, and

in the work of the many thinkers who have been directly or indirectly influenced by him. Perhaps a rough analogy drawn from scientific practice will make it clearer. Many mathematical notions, such as that of continuity, are made practical use of, long before they receive satisfactory logical definition. The successive definitions are at each stage pushed to the limit of their functional value, closer definition following only as the need is felt for it. At any stage in the history of the conception, men knew what it meant in the first sense, for it was used in statements which conveyed significant information. But at any particular stage he would be a bold man who claimed that he knew what continuity meant in the second sense. To take another instance, the Newtonian conception of fluxions, defined in terms of infinitesimal quantities, was of obvious practical use and significance, though the conception was riddled with ridicule by Berkeley. It turned out later that, though the conception had meaning in the first sense, even when it involved infinitesimals, yet its meaning in the second sense was only known adequately after more fundamental analysis had expressed it in terms of limits.

The analysis employed by critical philosophy is not directed to undermining common-sense, but to refining it. Moore goes further, of course, and contends that we abandon common-sense only at the risk of finding ourselves unable to make significant statements at all. That is perhaps why he took, as the motto of his first book, Butler's pregnant saying "Everything is what it is and not another thing"; for in it he expounds the view that Good as a predicate cannot be defined in terms of anything else. It is taken for granted that we know what we mean (in the sense of understanding the words which express them) when we make moral judgments, and that we understand in precisely the same way as when we make judgments of perception. Logically the problem of ethics is on a par with the problem of physics. "In both cases" Prof. M. R. Cohen points out "we may be said to begin with a set of primitive judgments—in the first case that certain things exist and in the second case that

they are good or ought to be. . . . The greater difficulties of a theory of ethics are due to the greater variability of man's moral judgments and their dependence on all sorts of conventions which differ according to time and place." The lively co-operative discussion of these problems now proceeding among the Oxford group of moral philosophers is being conducted in something of the same spirit, though on different lines. They take their start in reaction against what was left of utilitarianism in Moore's ethical view. Moore had left Right as meaning an act the total effects of which are at least as good as those of any other act which the agent could have performed instead. For him, the business of ethics is primarily the determination of what things are intrinsically good. This means, however, that judgments concerning what is right involve judgments of means to ends in a complex world of social beings, instead of being intuitive like judgments of good. That is why the Oxford discussions began with Prof. Prichard's contention (in the manner of Moore) that previous errors of treatment of Right sprang from the initial fallacy of supposing that moral philosophy is engaged in giving reasons for holding that what we think to be obligatory is really so—a fallacy exactly parallel to that of supposing that theory of knowledge is concerned with the question as to whether what we think to be knowledge is really so. Just as in knowledge we begin and end with the intuition 'this is true', so also in morals we begin with the intuitive judgment 'this is right'. The work of philosophical analysis in ethics is then directed to finding out the structure of what must be the case if propositions expressing judgments of these kinds are true.

The more factual temper of this general attitude is evident when we contrast it with the utterances of those who do not realize the similarity between moral judgments and judgments of perception. Thus Prof. L. Hogben excludes moral (as well as political and æsthetic) phenomena from rational treatment, on account of their 'private' character as contrasted with phenomena which are 'public' in the sense of gaining universal assent. But surely all men do in fact make

moral judgments, just as they all make judgments of perception. He himself, for instance, makes moral judgments: as when he says that "Our expectation of life has increased as we have learned to worry less about the good life and more about the good drain." It is a sentiment with which I am in hearty sympathy: but it implies the moral judgment that increased expectation of life is good. And such moral judgments are phenomena as solidly real as any other facts in our world. They are part of the "choir of heaven and furniture of earth." They can therefore, presumably, be viewed critically and systematically. Prof. Hogben can only mean, by excluding them from rational treatment, that all attempts to render them intelligible have failed. This seems, at one and the same time, to be (*a*) unduly sceptical since some moral (and political and æsthetic) order is discernible in the world; and (*b*) unduly dogmatic, since the comparative failure of previous attempts at discovering order may be due to incomplete, rather than to incorrect, procedure. It may be that, though there is an objective order to be discovered in these realms, it is harder to find. It has been suggested by many writers that we occupy the same position in regard to our moral and æsthetic judgments as children do in respect to their judgments of material things. Thus Dr. P. B. Ballard, after describing children's difficulties over even the simplest observation of spatial properties, goes on to say that in dealing with aspects of the physical world we are their superiors: we are more or less grown up. But in dealing with spiritual things we are still little children. "Our blunders are little children's blunders, due to our fumbling after a dimly seen reality."

It may turn out, as here suggested, that our deficiencies in these domains will disappear as the human race sheds its more infantile characteristics. An essential factor in this development is improvement in our understanding of ourselves, and of these other sides of our experience—our relationship to the world of society and to the world of values. More alert understanding of these is, indeed, an essential pre-condition for control of our destiny. Mr. Julian Huxley

has suggested that the biological sciences are now in the position occupied by the physical sciences at the middle of last century, when they were about to start on their triumphant series of applications to man's control over the material world. Enough knowledge already exists, he contends, for us to achieve our main biological desires of living longer; of moulding the bodies, intellects and temperaments of our children into the best possible forms; of creating new kinds of animals and plants at leisure; of keeping the balance of nature adjusted in our favour; and of controlling population and improving its quality whilst retaining variety. But before such knowledge can be applied we have to be able to work clear of ancient loyalties, of powerful prohibitions and observances, which bind society in unreasoning conservatism. Only rational treatment of psychological, as well as biological, fact can help us in this task. We must now turn, therefore, to the methodological issues raised by these less mature studies.

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Biological science, occupying an intermediate position between the physical and the social sciences, is rapidly taking on some of the characteristics of the former. It is achieving wider generalizations, and enjoying the added power which comes when measurement can be applied. It is often asserted, and more often implied, that there can be no science without measurement. This is a mistake. There can be purely qualitative ordering of facts in any field: and in the development of all the sciences qualitative ordering naturally comes first. Measurement does not change the character of the process; though it is an advance which involves, logically, the long step from merely serial to quantitative relations. Moreover the difficulty of taking this step correctly is the same in all domains.

When we turn to the less mature social sciences qualitative ordering is still in the ascendant. But that is the only difference. Facts are manipulated in these sciences in ways which are formally similar to their treatment in the maturer

sciences. For they have to be arranged in groups which will bring out their significance: attention has to be focussed on certain properties which will allow the construction of concepts as bunches of properties, and permit the passage to still more general concepts by inductions of a higher order. Dr. Wrinch-Nicholson has shown in a very interesting way that this procedure is exactly describable in terms of that general science of classification which we call geometry. "Scientific theory is the geometry of facts."

The trouble in the social sciences does not come from difficulty in such classification, but from our inability to face the facts squarely as a preliminary to discovering their more fruitful groupings. Our view is obscured by previous, and emotionally held, systems of classification. In our age many students of the physical sciences, living in a realm of wide generalizations, need the bladder-boys of Swift's satiric imagination to bump them back to the world of common things. Students of the biological and social sciences are not likely, for generations to come, to fall into this error. *Their* difficulty is the opposite one of failing to work themselves clear of whole bodies of traditional beliefs, customs and habits. Man's first passion is for order. He desires security in society, and certainty about the world. This means that facts which fall outside a given system have not only no significance for the primitive mind: they are not observed at all.

This was the position, of course, in all sciences during their early stages. But it is necessary to stress it here, because it probably forms the real ground for the popular prejudice against treating social phenomena 'scientifically'. The very objectivity, the 'ethical neutrality' of a scientific methodology renders it inapplicable (it is supposed) to any but an 'ethically neutral' subject-matter: as if it were really true that "Who drives fat oxen must himself be fat". It must be obvious that ethical neutrality of method does not necessarily mean that the subject-matter need be.

Apart from these considerations, the problems raised by the social sciences are similar in form to those raised by physical science. Only, in these less developed domains some

of the dangers we have already mentioned become more serious. We will deal with two of these in detail.

In discovering the order embodied in a collection of facts we must not, in any science, force that order beyond what the facts themselves warrant. We have spoken of science as the reducing of a complex of facts to intelligible order: yet we must always be prepared to find that some facts remain stubbornly irreducible to any 'order' we are likely to discern. Indeed the factual discrepancies in a theory are the rough edges of the building, showing where the next advance is likely to be. It is myth (and not scientific generalization, with its successive approximations to truth) which panders to man's thirst for finality. "It is the chief glory of science" Prof. Hogben rightly remarks "that its answers are always incomplete."

Though all this is obvious, it is not often recognized as fatal to any really tough-minded determinism in these fields. A 'methodological determinism' is still, of course, defensible —since it encourages us to look for order everywhere. Even in the very citadel of apparent disorder, statistical law may be achieved: laws which include (as Mr. J. D. Bernal has pointed out) what is in effect the chance interactions of complexes of a lower order. "The death-rate of a town, for instance, can be shown to be a function of the amount of money it spends on sanitary measures; but the individual deaths appear, from the point of view of the town, to be due to chance circumstances, though for each individual concerned they are determined." Nevertheless, if we wish to adopt a properly scientific attitude we must firmly decline to go beyond accepting 'order' where we can find it, and must be prepared to take 'disorder' at its face value too—without venturing to say whether it is ultimately disorder or not. When Freud finds that he can explain the facts relating to the slips and errors of everyday life by means of ordering conceptions such as 'dissociation' and 'conflict', we may accept his actual findings without being bullied into going further and asserting a universal psychological determinism.

But this is not all. For when we begin to apply such know-

ledge as is provided by 'order' of this type, we come upon the curious conclusion that the more we know about our activities the better are we able to control them. When we learn, for instance, that our outbursts of angry annoyance over trivialities can usually be traced to a more solid underlying cause, it makes such incidents not only more interesting, but also less likely to happen. In short, the more we know of the conditions which determine our own behaviour, the freer we are. For once we have dragged the factors influencing it into the daylight of understanding, we are less at their mercy. Those who believe in freewill as a dogma are always uneasily disturbed by the working assumption of every science that all events form a causal series. They do not realize that without knowledge of such a series there is no intentional activity: that the more we know of the causal series, the greater the control. I do not pretend to understand this paradox, I merely commend it to your notice. Life can be regarded as an observed developing order (not apparently inconsistent with freedom) in contrast with that continuous drift back to disorder in the material world which is indicated by the greatest of our statistical generalizations, the second law of thermodynamics. If this is determinism, it is determinism of a non-finalist type.

In precisely the same way we are led (as another consequence of the rule not to pass beyond what order the facts themselves warrant) to limit sharply our working assumption of mechanism. For each science is an autonomous study in the sense that the worker in each field can alone determine the effective form of the concepts he requires for ordering his particular domain of experience. He can therefore legitimately set his face against any attempt to force upon his study categories foreign to it. It is true that the methods of the various sciences are similar in structure: and that therefore the less mature sciences will continue to find reference back to the more mature—a fruitful methodological principle. But to go beyond this is to go further than the realities of the case warrant.

Let us consider, for instance, the relation between

psychology and physiology. There is, in my opinion, a good deal of loose thinking about their relationship: and it might be worth while to try to differentiate between these two studies. The human creature is being perpetually stirred to activity either by influences coming from outside, as when I blink at a threatening gesture, or make the 'response' of hunger to certain bodily changes (my body being regarded, in this connection, as 'outside myself'); or by influences which seem to come from within, as when I suddenly remember a forgotten engagement and dash for my hat. In observing myself I can easily make this distinction between response to a stimulus, and activity initiated from within. But in observing other people, and still more in observing animals, it is difficult to be sure about it. The behaviourist of course denies the right of the observer to make use of his own consciousness—a view difficult to accept, since if he is not conscious he can observe nothing at all. We may, then, adopt either of two complementary ways of looking at a living creature's activities from outside. We may either regard them as more or less complicated variations on the simple response-to-stimulus theme; and these may be purposive, since they are often adapted to achieve an end, as when my blinking protects the eye from danger. Or we may regard them as the expressions of strivings: purposive also, but directed towards, as well as adapted to, the ends of the activity. Of these two ways of dealing with the organism's activity, the first comes more naturally to the physiologist; the second, to the psychologist. The physiologist therefore seeks interpretations of the living creature's activity in terms of physico-chemical mechanisms involved in its responses: the psychologist, on the other hand, looks for interpretations of the same facts in terms of what he knows of living activity from his own consciousness of it. In this lies the distinction between these two cognate and overlapping sciences.

Now I do not believe that we are scientifically justified in assuming either (1) that all the acts of living organisms are of the striving kind—a view like that of McDougall; or (2) that all behaviour is reducible to the 'response-to-

stimulus program.' I hasten to say that I believe that behaviourists are performing a very useful work in showing us what an unexpectedly long way we can go in studying behaviour, without using terms drawn from conscious experience. But my own feeling on the whole question is that we must take up the same attitude here as we did to the problem of determinism. The psychologist, as a man of science, seeks to interpret the activity of living creatures in terms of striving. When he can do so, well and good. But sometimes he cannot. There may be acts, corresponding to what we have previously called disorderly facts, which cannot be ordered in these terms. And there may be others which are more simply rendered intelligible in terms of the ordering conceptions of physiology. We must greet behaviouristic successes with a cheer. This seems to me to be the only strictly scientific attitude. Moreover, it embodies the methodological principle that we should never postulate a higher level of behaviour than what is strictly required to account for the observed facts. Here is, I suggest, Occam's razor of social science. If this is mechanism, it is the mechanism of a peculiarly Pickwickian kind.

The hypostasization of ordering conceptions is the mark of a younger science; but it has more serious effects in the social than in other sciences. One of the oddest things in the history of thought is the astonishing way in which men have always mixed up what they actually observe with what they (often precariously) infer from their observations. I suppose that if they did not do this the barrister's work of cross-examination would be impossible—consisting as it does in persuading a witness to add to his evidence of facts the barrister's own inferences from them. In scientific work it is this kind of confusion which makes it easy to think of 'facts' and 'ordering conceptions' as of the same type. It leads us to hypostasize our concepts. So far as the physical sciences go hypostasization of ordering conceptions has ceased—except as a preliminary process, until a more generalized type of explanation becomes possible.

In the younger sciences, as we should expect, it is not yet

recognized that the ordering conceptions are only one step towards generalized descriptions of phenomena which shall contain only observable factors. Active principles—forces, chemical affinity and the like—have disappeared from physical science: but they flourish in the social sciences. Thus conceptions such as Instincts or the Unconscious are not regarded as merely bringing observed facts of behaviour into orderly connection with one another, but as active and existent entities 'causing' the creature to behave as it does. They are looked upon as inner driving forces urging the organism to achieve the ends of its being. In the same way Evolution is often regarded as a sort of force, instead of as the merely descriptive conception which it is. If there is an active unity behind evolution, it is something inferred, but not observed. Prof. Ginsberg has analysed what is essentially required in the concept of Evolution, and has shown that all the methodological requirements are met if we say that Evolution asserts that there are immanent factors involved in the observed processes of change. That is to say, when it is possible to describe a body of fact in evolutionary terms we may infer that immanent causality is involved. Notice that this is formally similar to my suggestion that if a group of facts can only be adequately described in psychological terms it implies that conscious striving is involved in the observed processes. Prof. Ginsberg puts forward this way of regarding Evolution as a more desirable method than the earlier usage which implies the persistence of an identical subject or unchanging substance. The same tendency is even observable in theology, the systematic study of man's religious experiences. For it shows a progressive movement from cruder anthropomorphic conceptions of Deity towards more objective ones—to forms, indeed, transcending personal theism altogether.

The trouble about these 'active principles', when they are not regarded as mere descriptive devices, is that they are ready to hand when passion needs them—to wave like banners in the face of every contradictory fact. Myths, after all, are only hypostasized ordering conceptions which have

outlasted their time. Yet most of our unreasoning loyalties, in social affairs as in science, are nothing but the worship of unreal, and often personalized, entities of this type. These make it easy for us to read more unity into the world than there actually is. We are thus led to rely upon divine or evolutionary purpose instead of upon our own efforts. There is created, in this way, a feeling that the incidental poverty and dirt and disease in the world must be part of a pre-formulated plan: these become, indeed, somehow sanctified by resigned acceptance of them. Rational thought, which regards poverty and disease and dirt as preventable, is therefore felt to be something divorced from the life of the spirit. The old attitude of resignation must be replaced by one which encourages man to make the fullest use of his intelligence for the improvement of his lot. The problem of evil, when this has been achieved, will be (in Vernon Lee's phrase) the problem, not of its toleration by God, but of its diminution by Man. It is an attitude, however, which (whilst depending upon a unified view of man as a whole) nevertheless refuses resolutely to accept the easy comfort of unjustified unities in the world. We must therefore enquire what light philosophical studies throw upon this latter question.

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We have seen that the main current in philosophy is flowing in the direction of analysis. The extreme position is represented in Bertrand Russell's statement that the most fundamental of his beliefs is that "the universe is all spots and jumps, without unity, without continuity, without coherence or orderliness, or any of the other properties that governesses love." This view is ultimately based on an attitude to causality which is as old as Hume's, in which causation is identified with regular sequence. Hence, though Russell regards science as confined to dealing with the causal properties of things (though these do not exhaust the rich concrete variety of the world), yet this does not involve, on his view, any sort of rational system among the world of events in time. For strictly speaking one cannot infer any

material fact from another material fact: they merely happen together, and create an expectation of their happening together in the future. "Of unity, however vague, however tenuous" he says again "I see no evidence in modern science considered as a metaphysic. But modern science considered as common sense remains triumphant, indeed more triumphant than ever before."

I fancy that most people will find Russell's psychologism as unsatisfactory as Eddington's subjectivism. They will feel that 'expectations' so solidly grounded in experience must be more than mere conditioning of men's minds, and have some objective reference to an order in the world. So we are led back full circle to those older schools of philosophy which held that the possibility of rational treatment implied a rational world. In these it is often assumed, as in Spinoza's system, that the connection between cause and effect is identical with or closely allied to that between ground and consequent: and that everything in the world we know, is therefore, directly or indirectly, causally related to everything else. The world is a logically intelligible system; and the nature of any one thing taken by itself is incomplete and internally incoherent apart from the system on which it depends. This kind of view provides us with our other extreme. Our choice is between reality as a rationally intelligible system, and reality as a mere aggregate of brute facts. Probably the truth is somewhere between these two. It may be, as Dr. A. C. Ewing has recently suggested, that philosophical analysis of causality has not gone far enough. He shows that, as used by common sense and science, we assume that there is something more in causality than regular sequence. Just as in perception we can analyse our sense-data, and yet feel uncertain as to how these are related in the structure to which a true judgment of perception refers; so also in judgments concerning caused events we can analyse out regular sequence as one factor, and yet not know how exactly it is related to other (as yet unanalysed) factors in the structure to which a true judgment of caused events refers. Causality is for Ewing "the application to events of the principle of system, which

is a cardinal assumption of thought, whether this principle be conceived as a pragmatic postulate verified by success, or as a necessity of logic, or as a perhaps somewhat dim and confused but nevertheless genuine intuition of the nature of the real world." Such a 'principle of system' we shall doubtless continue to use, even if we feel too unsure of its meaning (in Moore's second sense of that term) to feel that we can assert with certainty what kind and degree of systematic unity the world really possesses.

Another way of putting the analytical position is to deny the possibility of a purely deductive metaphysic. The difficulty for those who believe in deduction as the method of arriving at knowledge is that they are compelled to find their premisses somewhere. They may take them from a body of sacred writings; or they may discover them in indubitable fact, like Descartes. In either case they are likely to be involved in "the finding of bad reasons for what we believe upon instinct"—in explaining concrete facts away, instead of just explaining them. This is how Prof. L. S. Stebbing has expressed the position. She admits that rejection of a purely deductive metaphysic involves discarding a conception of philosophical method which has yielded results of great significance for human thought; and adds that, in the hands of a philosopher who did not set out to find reasons for common-sense beliefs, but merely to expound a vision, such systems may have their proper function and possess the beauty of works of art. "Hence their spiritual significance. They heighten the joy of living." She concludes, however, that they do not give knowledge: metaphysics does not consist in creation but investigation. This amounts to the same thing as the remark of R. Carnap, a Continental representative of the analytical school, that "metaphysicians are musicians without musical capacity"—a sentiment in perfect accord with Wittgenstein's "Whereof one cannot speak, thereof one must be silent".

This analogy between philosophical systems and works of art enables us to understand the perennial appeal of the great constructive systems of the past. For they are attempts to

make man see, grasp, comprehend the bodies of knowledge he has won: see them, not separately as the various sciences see them, but together—a true synopsis. That is why William James could speak of philosophies as "just so many visions, modes of feeling the whole push and seeing the whole drift of life"; and why we can speak of such constructions as architectonic conceptions which illumine not only the thought of our time, but may even strike a light for future ages. In so far as they do this, they are a sort of prophetic science. The history of philosophy is therefore very largely concerned with the herculean labours of great minds to do something which can only be achieved by the advance of the sciences. It is not therefore useless. To know what the acutest minds of each generation have considered to be the structure of the facts then known about the world will give us historical perspective, by retailing the tortuous tale of human error, and by putting up warning barriers at ways which have turned out to be dead ends. The latter may be useful to physicists when they discover, late in the day, that mind has a part to play in knowing, and so tend to exaggerate it.

The philosopher will always be called on to make efforts at synthesis because the generality of his studies marks him out as the obvious person to attempt the impossible. That is what the philosopher is for. And I see no reason why he should not do so, provided that he remembers (as I remarked at the beginning) that in going 'beyond science' he is exercising his prophetic rather than his purely philosophical powers.

This is where studies of man 'in the round' come to our aid. For we are carrying into a new era sets of emotionally tinged presuppositions which have served us in the past, but may now, in altered conditions, bring ruin upon us. Such hindrances prevent us, in every department of social affairs, from organizing our civilization so as best to serve the ends of human well-being. Clearer vision of our mental deficiencies is needed if we are to apply our knowledge to a world where the blunders of our ancestors have come down to us in our blood and in our institutions. Increased critical acumen is an ally in this struggle.

But knowledge, and the control it brings, only marks the beginning of our main problems. We have to learn to use wisely and well the new instruments placed in our hands. This is what calls for construction. Man has risen above the unreflective animal level not only by attempting to understand his experiences but also by evaluating them. Culture, as Whitehead has said, is "activity of thought, and receptiveness to beauty, and humane feeling." Just as there are human beings more than normally endowed with understanding, so there are those that are stung more keenly by beauty, and others that surpass the common run in sympathetic insight. It is to these gifted souls that we look for guidance, so that we may take the order they reveal to us—intellectual, æsthetic, moral—and weave them into the texture of the work-a-day world. We have to catch something of the vision of sage and artist and saint; and we have to embody their visions in the social order.

Can the constructive hints of 'synoptic science' help us in this task, even though analytical philosophy should withhold from us (in its scrupulous regard for intellectual honesty) any certainty about ultimate structural unity in the universe? I think it possible. A more generous view of man and his world would assist us in applying our knowledge wisely by ridding us of some of our fears, and by bringing into the daylight of understanding the factors involved. The old attitude of timorous resignation might thus be replaced by one of hopeful fearlessness—a new frame of mind which may well prove to be, for a brighter era, what belief in Providence has been for the old: a remedy for despair, a vitalizing conception to keep man marching breast forward to the future through every danger and disappointment. The all-in character of philosophical studies gives them a constructive part to play in such social engineering. They should prove serviceable, even if sometimes disconcerting, collaborators in drafting the blue-prints of a new order.

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